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Review of DNA Remote Security Station (RSS) Project Phase 1

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REVIEW OF DNA REMOTE SECURITY STATION (RSS) PROJECT PHASE 1

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ABSTRACT

This report reviews the progress made during FY87 on the Defense Nuclear Agency(DNA) sponsored Remote Security Station (RSS). During this time frame, Sandia National Laboratories was tasked to develop a Phase 1 proof-of-principle system consisting of readily available hardware. The primary emphasis was placed upon development of software and sensor fusion techniques, and as a result the Phase 1 hardware is not suitable for field deployment. The RSS consists of a portable (non-mobile) sensor platform and an intelligent controller. The paper includes descriptions of the sensor platform and control console hardware, as well as the software that runs the intelligent controller. The sensor fusion techniques originally considered are discussed, and the methods used in the current system are explained in detail. Phase 2 development of the RSS is scheduled for FY88, and a discussion of the planned improvements is included. Keyword: Intrusion Detectors. (jhd)

1. INTRODUCTION

The purpose of the RSS project, which began in mid-FY87, is to develop a robotic sensor platform to enhance a fixed-site security control center by providing localized detection and assessment. The intent is (1) to improve detection, primarily by reducing the false alarm rate (FAR) through sensor fusion and alarm analysis techniques, and (2) to improve assessment by cueing the operator with the location of the threat. Phase 1 concentrated on developing sensor fusion techniques rather than hardware. The goal was to demonstrate in October 1987 a "Proof of Principle" (POP) Remote Security Station using laboratory hardware. A field prototype RSS will be built in Phase 2, and it is anticipated that the Phase 2 sensor suite will be incorporated on a mobile platform in Phase 3.

Copies of the viewgraphs used for the project review are included in Appendix A.

Applications of this type of robotic sensor platform for fixed-site security include use at both temporary and permanent locations, and use as a mobile sensor platform. A portable platform could be used for temporary enhancement or replacement of existing Intrusion Detection Systems (IDSs). For instance, if an intrusion is likely at a particular point, or if some part of the IDS is isolated and vulnerable, a portable platform could augment an existing system or be positioned to replace faulty components of an existing IDS until they are repaired. Another situation where a portable RSS would be beneficial is to protect high-value assets that are present only for short periods of time--for instance, if an aircraft or special transporter is parked where installation of permanent IDS sensors would be impractical.

Examples of permanent locations of a robotic sensor platform include using it to cover specific high-priority locations in a hardened fixed configuration, on a tower, or in an unobtrusive pop-up shelter.

Mobile applications would offer even more benefit from a robotic sensor platform. A teleoperated or autonomous mobile sensor platform could provide greater detection and assessment capabilities than a stationary platform because of its ability to cover larger areas. A vehicle-mounted RSS that could autonomously patrol certain areas of a fixed site would free operators at the security control center for other tasks until an alarm required their direct attention. If the platform included delay or deterrent devices, these devices could be safely activated from the security control center without placing personnel in potential danger.

The major components in this POP Remote Security Station include the following:

- Sensors for detection, assessment, and environmental monitoring.
- A portable (nonmobile) pan/tilt sensor platform, or pod, which can be teleoperated manually or computer controlled.
- A nonportable intelligent controller, located in a security control center that includes processors and the operator's interface.
- A communications link consisting of individual cables for transmitting power and data between the sensor platform and the intelligent controller.
- Sensor fusion methods that include sensor combination, alarm prioritizing, assessment cuing, and image processing, with emphasis on alarm prioritizing and image processing.

2. DESCRIPTION OF THE HARDWARE

To meet a tight schedule, the Phase 1 system was assembled with common, off-the-shelf hardware that had short delivery times, was available on loan, or was left over from inactive programs. The POP system is not suitable for field use since it is inefficiently packaged and not weatherproof. The sensors in this laboratory prototype system are intended to be representative of those that might be required in a fixed-site application, and are used here to demonstrate sensor fusion techniques. Figure 1 is a block diagram of the Phase 1 RSS system.

Sensors

Both security and environmental sensors were included in the Phase 1 RSS.

The security sensors include:

- Cohu B/W CCD TV camera used for both detection (with the Video Motion Detector (VMD), described below) and assessment.
- Eltec Passive Infrared Motion Sensor (PIMS), also called an infrared (IR) telescope because of its narrow field-of-view (2 degrees), used for detection.
- Sandia-developed acoustic array that identifies the bearing angle of acoustic targets (see Appendix B for details).
- Bionic Ear directional microphone used for assessment.

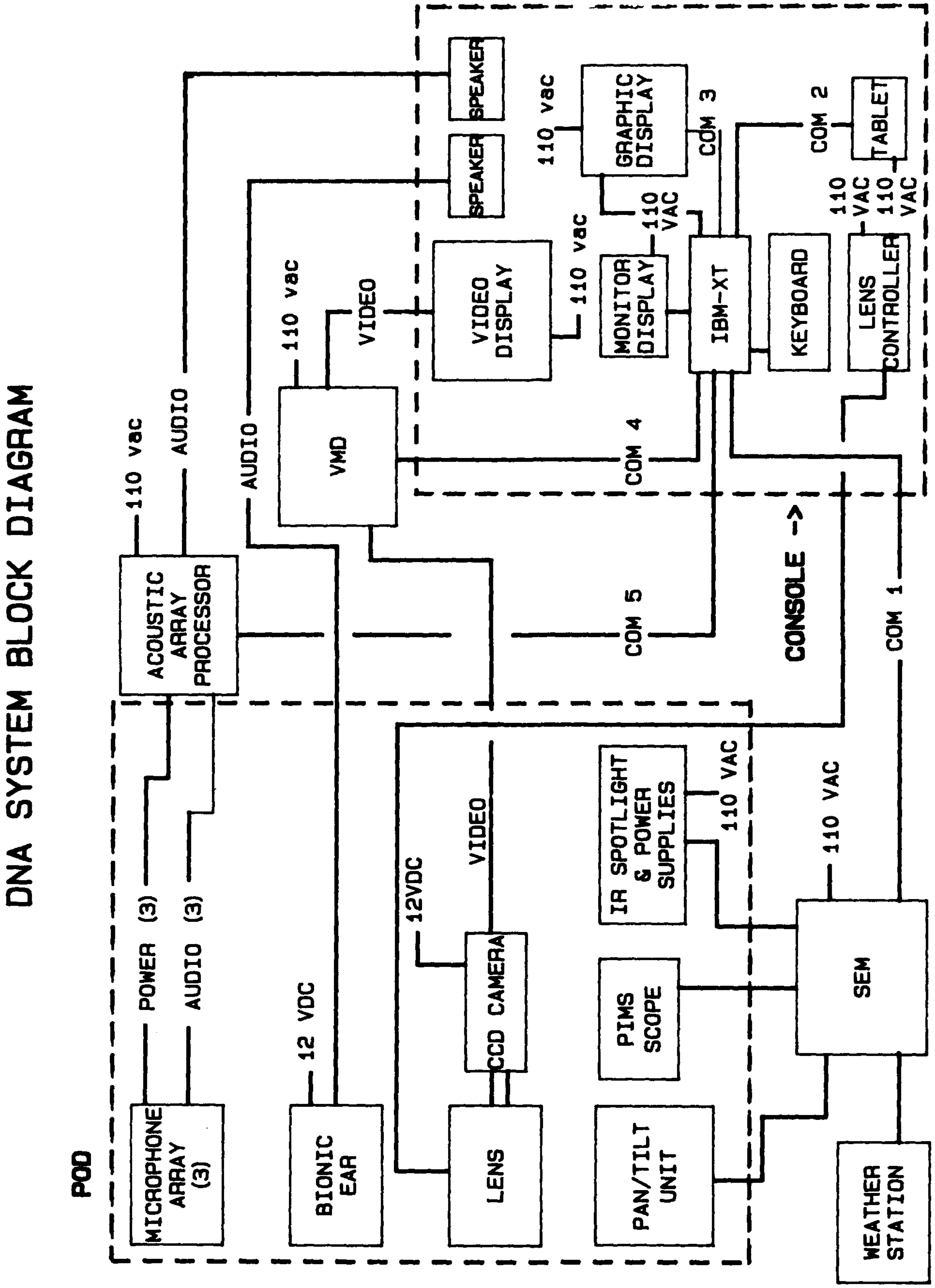
DNA SYSTEM BLOCK DIAGRAM
POD
CONSOLE ->
MICROPHONE ARRAY (3)
POWER (3)
AUDIO (3)
BIONIC EAR
12 VDC
LENS
CCD CAMERA
12VDC
VIDEO
PAN/TILT UNIT
PIMS SCOPE
IR SPOTLIGHT & POWER SUPPLIES
110 VAC
SEM
WEATHER STATION
COM 1
ACOUSTIC ARRAY PROCESSOR
110 vac
AUDIO
COM 5
VMD
COM 4
VIDEO DISPLAY
SPEAKER
SPEAKER
MONITOR DISPLAY
GRAPHIC DISPLAY
COM 3
IBM-XT
KEYBOARD
LENS CONTROLLER
TABLET
COM 2
110 VAC

Figure 1

- Infrared (IR) spotlight that provides a night-vision capability by taking advantage of the CCD camera's ability to operate in the near-IR region. This device provides illumination for the ccd camera while remaining invisible to the naked eye. (This is the only active device on the RSS.)

Other security sensors considered were a forward-looking infrared imager (FLIR), seismic disturbance detector, monostatic microwave motion sensor, laser range finder, acoustic helicopter detector (SHAD), and a Ground Surveillance Radar (GSR). Arrangements were made through DNA to borrow a GSR for evaluation.

Sandia National Laboratories (SNL), Exploratory Systems Development Division 9133, has developed image-processing algorithms that alert to meaningful motion occurring in a video image. The image can be generated by several types of imaging devices such as a TV camera, thermal or laser imagers. The RSS uses a black-and-white CCD camera as input to this VMD software. However, it only functions when the sensor platform is stationary, and for motion in the sensitized portions of the camera's field-of-view as set up by the operator.

The environmental sensors incorporated in the laboratory hardware RSS measure light level, temperature, humidity, and wind. They were part of the Sensor Environment Monitor (SEM), which was developed to monitor the environment of interior intrusion detection sensors. Therefore, these sensors were never intended to witness the extremes of exterior environments and are not weatherproof.

Remote Sensor Platform

The remote sensor platform, shown in Figure 2, consists of intrusion sensors mounted on a pan/tilt platform supported by a tripod, three acoustic array microphones located 120 degrees apart on the ground about 1 meter from the center of the tripod, the environmental sensors, and the pod controller placed nearby. Cables from the controller supply the necessary 110 VAC power to the pod.

Controller

The intelligent controller will be located at a facility security control center where normal 110 VAC power is available. The POP system is housed in two slope-front racks with a desk top panel. The operator's control console (Figure 3) contains a video monitor, digitizing tablet and graphics display, host computer, keyboard, and computer display. All instructions and controls are input through the keyboard except for audio speaker volume, IR spotlight controls, and TV camera lens zoom and focus. Two

Figure 2. Pan/Tilt Platform

Figure 3. Operator's Control Console

speakers provide audio from the directional microphone and one of the acoustic array microphones. An IBM/XT is the heart of the intelligent controller. VME chassis used for the acoustic targeting and the Video Motion Detection (VMD) image-processing systems are also housed in the racks.

3. SENSOR FUSION

Introduction

Sensor fusion applied to intrusion sensors should reduce false alarm rates (FAR) and improve the probability of detection (PD). It can be approached in many different ways. Sensor combinations were considered, but most of the effort was concentrated on sensor alarm prioritizing, then assessment cuing and image processing were added. Common methods of combining sensors alarms include simple "and," or "or" combinations, and a more complicated "time regulated alarm combination" (TRAC). TRAC requires multiple alarms on the same sensor or on multiple sensors in certain time-period combinations before an alarm is reported.

Assessment Cuing

Assessment cuing can aid the operator in alarm assessment by providing information about the type of alarm and its location. The sensor platform can then be aimed at the alarm location for assessment either automatically or semiautomatically. In automatic mode, the platform responds to an alarm by moving until the camera's field-of-view is centered about the alarm azimuth. In the semiautomatic mode, the controller indicates the alarm azimuth and asks the operator if the platform is to be turned to that bearing. Upon the operator's command, the platform is turned to the alarm bearing under computer control. The operator can also control the platform in a totally manual mode. Currently, the acoustic array is the only omnidirectional intrusion sensor, and the only input that can automatically drive the platform to an azimuth bearing different from where it already points. Detection by the other sensors on the platform is limited to their fields-of-view, which are coincident with the camera's field-of-view. Additional detectors, such as perimeter sensors from a facility's Intrusion Detection System (IDS), could be tied into the RSS as other sources of alarm information to drive automatic assessment.

Image Processing

The image-processing system was explained earlier in Section 2.

Alarm Prioritizing

Alarm prioritizing received most of our attention for this POP phase. The prioritizing factors considered area:

- Weather
- Threat analysis
- Location of alarm
- Alert status
- Operations schedule, and
- Recent alarm history.

Section 4 discusses these factors in detail.

4. ALARM PRIORITIZING

The Weighting and Thresholding Concept

Alarm prioritizing methods of sensor fusion attempt to establish the importance of each sensor alarm through a concept called "weighting and thresholding." Only alarms with enough importance (weight) are presented to the operator to reduce the number of complex judgments the operator must make under stress. Alarm priorities are determined by considering many factors whose interrelationships may be site-specific. These factors must have thresholds established that can be based on measured parameters like temperature, or programmable selectors like time of day or location. The factor thresholds and sensor alarm believability weights (and, therefore, alarm priorities) will change with time and varying conditions.

The Phase 1 RSS demonstrates the weighting/thresholding concept by considering weather and location of alarm factors. Each alarm is weighted according to how the current environmental conditions affect the performance of the alarming sensor. The area around the pod is divided into 10 wedges of 36 degrees each, which radiate outward from the pod. Each wedge is assigned a threshold value from 0 to 100, that reflects the relative importance of the area or location within the wedge. The threshold values are inversely proportional to the area's importance. The sum of the weights of the sensor alarms occurring in each wedge during a given time period is compared with the threshold for that wedge. The system operator is notified only when the threshold is exceeded. For example, lower-weight alarms are reported in a high-priority wedge (low threshold) rather than in a less important (higher threshold) area. Appendix C discusses this weighting/threshold approach to sensor fusion in greater detail.

Weather

The effects of weather, specifically wind, temperature, rain, snow, humidity, and light level on individual sensors are fairly well known. The validity of sensor alarms can be judged by noting the current environmental conditions to determine if any condition exists that might reduce the reliability or sensitivity of a particular sensor. For instance, high winds will reduce the accuracy of the acoustic array target bearing determination; and ambient temperatures of 85 to 95 degrees F significantly reduce the sensitivity of the passive IR motion sensor. The intelligent controller automatically adjusts sensor alarm priorities for prevailing weather conditions.

Threat Analysis

Threat analysis is another factor that can be used to prioritize alarms. Intelligence sources or threat analyses may provide information such as location, mode of transportation, or timing of likely intrusions. With this knowledge, the appropriate sensors can be brought to bear, and the priority of these sensors raised to hasten detection and alert the operator. By knowing what stimulates each type of intrusion sensor to alarm, one can learn something about an intrusion. For instance, if the acoustic array identifies an acoustical target, the target is probably mechanized transportation and not a covert intrusion. If the target bearing is toward a critical location, it should be assessed immediately because the target might represent an overt intrusion. But if only motion is detected, either by the PIMS or the VMD, it is likely to be a covert intrusion. The PIMS' stimulus consists of heat sources moving across its narrow field-of-view (2 degrees) out to about 150 meters, while the VMD responds to meaningful motion in any direction by any object. The VMD detection zone is determined by the camera lens and the VMD setup and almost certainly is greater than the PIMS detection zone. Thus, even though the camera and PIMS are aligned, some possible discrimination of range, location, and alarm stimulus may aid in determining the type and location of threat.

Location of Alarm

The location of alarms is another way to prioritize alarms. The proximity of the alarm location to high-value assets, or the ranking of critical locations according to asset values can establish priorities. When alarm locations are very close to important assets, and if the threat is real, it means the intruder has almost reached the target, and the response forces should act immediately. If an alarm occurs far away from potential targets, it may be reasonable to wait for additional

alarms before responding, especially if there are significant delay barriers on the way to the target. On the other hand, if the expected target is very vulnerable, with no delay barriers and a "soft" enclosure, all alarms must be considered real and response time minimized.

Normally, if multiple sensors/detectors in the same vicinity alarm, then the validity of the alarms increases. But if security sentries or patrols are in the area, the sensor alarms can probably be ignored (and may even be caused by them).

Characteristics of the site geography can also determine alarm priorities. Geographic features such as steep hillsides or dense forest act as delay barriers themselves, so alarms outside them are not so important. These same hills (or buildings) may prevent timely assessment, however, and in that case, the response team or ground patrols should be alerted immediately for alarm assessment and containment of the threat. The RSS intelligent controller does prioritize alarms by location by assigning appropriate thresholds to the individual wedges.

Alert Status

The base or facility alert status effects how alarms should be handled. Some military bases use 3 levels of alert:

- Green alert. Things are normal and routine security measures are in order.

- Yellow alert. Security awareness is increased and guard posts and ground patrols are usually reinforced.

- Red alert. This is the highest level and calls for maximum deployment of security forces.

As more sentries and patrols are deployed, they assume detection and assessment duties, and sensors in the same areas can usually be deactivated. The presence of additional people may actually interfere with the operation of the IDS. When more security forces are deployed, they will probably be assigned to areas close to the high-value assets. Intrusion detection emphasis using sensors would then be shifted farther away from the assets to provide earlier warnings.

The intelligent controller could be programmed to automatically change the sensor alarm priorities as alert levels change. This relieves the operator of the responsibility of deciding which sensors are important at any particular time.

Operations Schedule

Alarms can be prioritized according to operations schedules. The RSS capability to desensitize specific areas permits it to continue detection and assessment at important locations while ignoring routine sources of movement or noise. Aircraft runways or motor pools are common sources of noise that could be masked to the omnidirectional acoustic array while it continues detection in other directions. The RSS intelligent controller could sensitize and desensitize both locations and sensors automatically according to the operations schedule, thus relieving the operator of this task.

Permanent IDS sensors occasionally must be deactivated for reasons stated above or to allow infrequent activities at the facility. For example, railroad shipments may not happen often enough to justify installing permanent security sensors to maintain perimeter security in the presence of the trains. An RSS could be used to maintain vigilance in the perimeter sector or zone containing the railroad tracks, while that portion of the IDS is deactivated.

Recent Alarm History

Finally, recent alarm history can be used to prioritize alarms. Successive false alarms on one sensor probably indicates a malfunction. The controller could automatically desensitize the alarms from that sensor until the problem is corrected.

If several intrusion alarms are activated in a sequence that indicates movement toward a suspected target, then the intelligent controller could report this real-time intrusion sequence of alarms as a high-priority alarm requiring immediate attention.

5. CONCLUSIONS

The FY87 effort for the DNA Robotics for Physical Security project was directed towards developing a proof of principle Remote Security Station using readily available hardware. This Phase 1 effort concentrated on developing the sensor fusion techniques used to reduce the false alarm rate and increase the probability of detection. Techniques to cue the system operator with the location of alarms, as an aid in assessment, were also developed.

The Phase 1 effort concentrated on developing software rather than building fieldable hardware. As a result, the Phase 1 system consisted of readily available hardware and little attention was paid to the packaging of the components. The basic algorithms and techniques for the intelligent combination of sensor information were developed, although field testing of the system needs to be pursued so that better estimates of weighting factors and thresholds can be obtained.

The RSS consists of several different intrusion detection sensors utilizing different technologies. By using a variety of sensors that are adversely effected by different environmental conditions, there should always be at least one sensor providing reliable alarm data. The fusion techniques used in the Phase 1 system exploit this concept by weighting the believability of each individual sensor in a summing function that produces "true" alarms. Presently, the environmental conditions at the sensor platform's location are used to alter the believability of alarms from each sensor. This should reduce the number of nuisance alarms caused by environmentally induced phenomenon. Future plans include adding the past history of a sensor's performance into this weighting function.

The Remote Security Station will be a valuable tool for security forces at both fixed and temporary sites. It has the characteristics of easy deployment, omnidirectional coverage, and a variety of intrusion detection sensors that collectively maintain reliable alarm information under all environmental conditions.

6. FUTURE DEVELOPMENTS

The DNA RSS is scheduled for Phase 2 development during FY88. This effort will improve upon the Phase 1 proof of principle hardware to yield a field prototype system. While the Phase 2 hardware will continue to be based on a stationary tripod, an eventual upgrade to a mobile platform is being considered in the design.

Several improvements will be made to the control console during Phase 2 development; these include better packaging, an improved operator's interface, and improvements in the fusion of sensor data.

Rack mount video and computer monitors have been ordered to replace the monitors currently in use; they should provide a cleaner installation and improve the appearance of the operator's console. The new computer monitor will be equipped with a touch screen; replacing the keyboard as the operator's interface to the system. The graphics tablet used to input site maps for the Phase 1 system was larger than necessary, so a smaller tablet that will mount nicely in the table top has been acquired. New equipment racks, suitable for mounting the new equipment have also been ordered.

As mentioned previously, a touch screen will replace the keyboard as the operator's interface. Experience with other security systems has shown that a touch screen is a very user friendly device. Rather than remembering keystrokes, the operator will

now simply be required to touch the proper area of the computer monitor. The menu driven graphics make it easy for an operator to learn the system. A joystick will be added as the interface to control pod motion in the manual mode. In addition to the manual and semiautomatic modes of operation, fully automatic control of the pod will be integrated this year. In this mode the operator will be required for assessment only, the host computer will detect an alarm, point the pod in the proper direction, and ask the operator to render an assessment.

The sensor fusion techniques employed in the Phase 1 system were limited to establishing wedge thresholds for alarm locations prioritizing and using environmental conditions to affect a sensor's believability or weight. A weighted sum of all sensors reporting alarms was then used to determine real alarms. This method is intended to reduce the false alarms caused by effects of the weather. No field testing of the intrusion sensors was done to determine exactly how they were affected by weather conditions or the optimal weighting factors to be used in the fusion algorithm. The environmental dependencies were subjectively based upon the past experiences of sensor experts at Sandia. Extensive field testing of the RSS intrusion sensors is planned to determine the proper weighting factors for each of the sensors. Inclusion of the past history of each sensor's performance into the fusion algorithm is also planned in the coming year. This should reduce the number of false and nuisance alarms produced by sensors for reasons other than environmental conditions.

The Phase 1 pod hardware was assembled with readily available components. No attempt was made to make the system ruggedized or weather proof. The Phase 2 effort will include repackaging the proof of principle components into a field prototype unit that is semi-rugged and weatherproof.

Several of the proof of principle components will be replaced for the field prototype pod. The Phase 1 pod required AC power to operate the pan/tilt motors; a new pan/tilt platform with DC motors has been acquired so that battery powered operation will be possible. A new directional microphone will replace the Bionic Ear on the upgraded pod. This new microphone is weather proof and should exhibit better performance. The camera, zoom lens, and IR spotlight are all susceptible to damage by moisture, so environmental enclosures will be obtained to protect these items.

Improvements to the acoustic array will be implemented as part of the Phase 2 development. Many nuisance alarms were caused by air traffic triggering the Phase 1 acoustic array. The planned

enhancements to the acoustic array will enable simple classification of noise sources, so that differentiation between helicopters, jets, and "other sources" can be attained. This should reduce the number of nuisance alarms originating from noise sources such as established air traffic routes.

Improvements will be made to the setup procedure for the video motion detector (VMD). The current procedure calls for setting several parameters that require an experienced operator to determine optimal values. This setup will be incorporated in the system so that at most the operator will be requested to answer a few simple questions. The computer will then set these parameters for the current conditions based upon a database of knowledge. The operator will also be required to define an area of interest at several key pan/tilt locations. The remainder of the setup will be taken care of automatically by the computer and the setup parameters will be dynamically updated with changing weather conditions to provide optimal operation at all times.

Two new sensors will be evaluated this year for addition to the RSS sensor suite; the AN-PPS-15 Ground Surveillance Radar (GSR), and the Southwest Microwave model #375A monostatic microwave sensor. No work has been done with either sensor, but plans are to evaluate their usefulness and incorporate them into the RSS sensor suite if they are found to be worthwhile additions.

The Phase 1 pod controller and weather station was based upon the Sensor Environment Monitor (SEM). Since the SEM was developed for use in interior environments, it was never intended to measure the extreme conditions encountered outdoors and the electronics are not packaged in a weather proof enclosure. The Phase II effort will include the fabrication of a new weather station and pod controller that is designed to measure exterior weather conditions. The new pod controller will be environmentally enclosed so that it is suitable for deployment in exterior environments.

Communication to the RSS sensor platform is currently achieved over individual copper conductors for each data, video and audio signal. Due to the lossy nature of the transmission of these signals over copper, the distance that the pod can be deployed from the control console is very limited. No tests have been conducted to determine the limit of this transmission distance, but it is on the order of several hundred meters for the current system. For this reason, a fiber optic communication system will be used for the Phase 2 RSS. Individual fibers will still be used for transmitting each of the signals, but these will be jacketed into one cable so that deployment will be easier.

Three copper conductors will be included in the communication cable for the purpose of power transmission; 120 VAC sent over

these conductors will be used to power a 110 VDC supply at the sensor pod. This DC supply will be used for nominal power requirements and to charge a battery that will be used during peak power demands, such as when the IR spotlight is turned on. The fiber optic modules are capable of transmitting signals over a distance of at least 3 Km, but due to losses in power transmission the remote power supply will only operate at distances of 1 Km or less from its 120 VAC source. This was deemed to be an acceptable limit to the distance that the RSS sensor pod could be deployed from the control console.

The many enhancements to the Remote Security Station planned for FY'88 should greatly increase the system's value as an additional tool to be used by security forces. Repackaging of the components will produce a system rugged enough to be deployed in the field. Improvements in the operator's interface will make the system easier to use. Finally, improvements in the sensor fusion techniques and the addition of more capable sensors will improve the performance of the system.

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Washington, DC 20545
Attn: DASMA, DP-20 (1)

Central Intelligence Agency
Washington, DC 20505
Attn: R&D Subcommittee (1)

Diplomatic Security Service
US Dept of State
Washington, DC 20520
Attn: DS/ST/SDE-SA-7 (1)

US Dept of State
Office of Security
Washington, DC 20520
Attn: Chief, Res & Dev. BR
A/SY/OPS/T (1)

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5230	M L. Kramm
5238	R. C. Beckmann

5238	L. A. Haden
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5249	R. H. Graham
5250	T. A. Sellers
5260	J. Jacobs
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5267	J. R. Kelsey
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5267	D. P. Jones
5267	J. J. Harrington
5267	D. E. Hubbard
5268	C. E. Olson
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APPENDIX A

VIEWGRAPHS FROM FY87

DNA RSS PROJECT REVIEW

DNA/RSS

PROOF-OF-PRINCIPLE PHILOSOPHY

- DEVELOP WITH LAB HARDWARE
- USE COMMON REPRESENTATIVE SENSORS
- PORTABLE SENSOR PLATFORM
- NON-PORTABLE INTELLIGENT CONTROLLER
- EMPHASIZE SENSOR FUSION

DNA/RSS APPLICATIONS

- TEMPORARY LOCATION
  - ENHANCE EXISTING IOs
  - REPLACE FAULTY SENSORS
  - TRANSIENT ASSETS
- PERMANENT LOCATION
  - FIXED/HARDENED
  - TOWER
  - POP-UP
- MOBILE
  - TELEOPERATED SENSOR PLATFORM
  - SEMI-AUTONOMOUS PATROL VEHICLE
  - DELAY/DETERRENT/WEAPONS PLATFORM
- SENSOR SELECTION APPLICATION SPECIFIC AND EASILY INCORPORATED

DNA/RSS

PROOF-OF-PRINCIPLE CAPABILITIES

	DETECTION	ASSESSMENT
PLATFORM DIRECTION	IR SCOPE-MOTION DETECTORS VIDEO MOTION DETECTION IR SPOTLIGHT	VIDEO--IR SPOTLIGHT DIRECTIONAL MIKE
OMNI-DIRECTIONAL	ACOUSTIC ARRAY OTHER-IOS	ACOUSTIC ARRAY MIKE
AIDS	LOCATION PRIORITY SENSOR PRIORITY ENVIRONMENT OPERATIONS SCHEDULE HISTORY	LOCATION OF ALARM TYPE OF ALARM/THREAT

DNA REMOTE SECURITY STATION

PURPOSE

DEVELOP A ROBOTIC SENSOR PLATFORM TO AID A FIXED SITE SECURITY CONTROL CENTER WITH LOCALIZED DETECTION AND ASSESSMENT.

IMPROVE DETECTION (REDUCE FAR)
- SENSOR FUSION
- ALARM ANALYSIS

IMPROVE ASSESSMENT
- CUING LOCATION OF THREAT
- IDENTIFY TYPE OF DISTURBANCE

INTENT

CONCENTRATE ON SENSOR FUSION DEVELOPMENT RATHER THAN HARDWARE

DEMONSTRATE A "PROOF OF PRINCIPLE" (POP) SYSTEM USING LAB HARDWARE OCT 1987

DNA REMOTE SECURITY STATION

MAJOR COMPONENTS

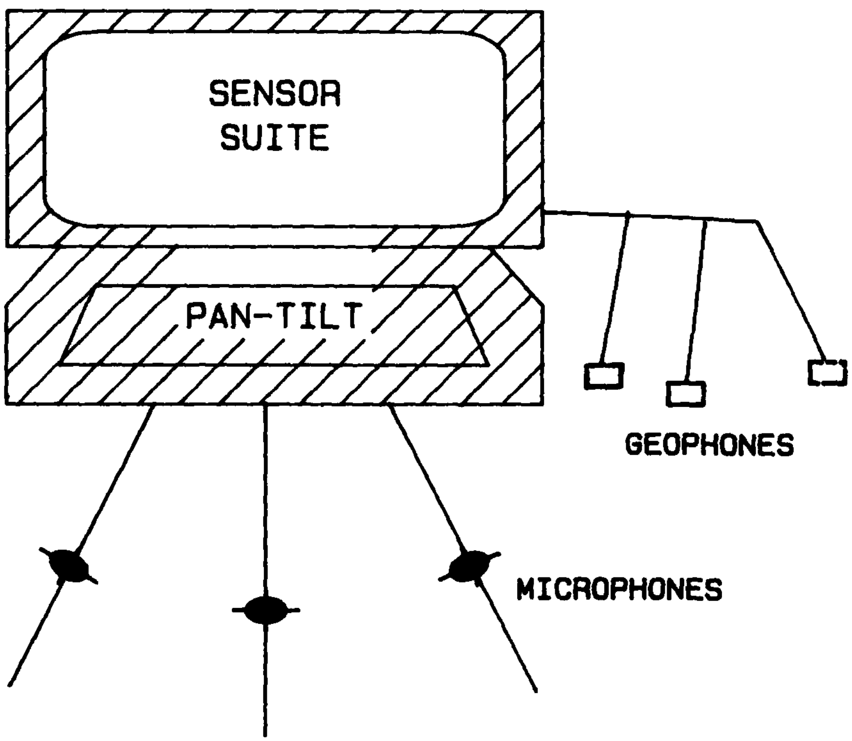
- SENSORS
  - DETECTION
  - ASSESSMENT
- SENSOR PLATFORM
  - PAN/TILT
  - MANUAL/PROCESSOR CONTROLLED
- CONTROLLER (NON-PORTABLE)
  - PROCESSOR
  - CONTROLS
  - DISPLAYS
- COMMUNICATIONS LINK
  - HARDWIRE FOR POP
  - FIBER OPTIC FOLLOW-ON
- POWER SUPPLY
  - 110 VAC FOR POP
- SENSOR FUSION
  - SENSOR COMBINATION
  - SENSOR ALARM PRIORITIZING
  - ASSESSMENT CUING
  - IMAGE PROCESSING

SENSOR FUSION METHODS

- SENSOR COMBINATIONS
  - AND
  - OR
  - TRAC (TIME REGULATED ALARM COMBINATION)
- SENSOR ALARM PRIORITIZING
  - WEATHER
  - THREAT ANALYSIS
  - LOCATION OF ALARM
  - ALERT STATUS
  - OPERATIONS SCHEDULE
  - RECENT HISTORY
- ASSESSMENT CUING
  - AIM PLATFORM
    - ACOUSTIC TARGET
    - SENSITIVE ZONE
    - MANUALLY
  - INFORMATION
    - TYPE OF DETECTION
    - LOCATION OF DISTURBANCE
- IMAGE PROCESSING
  - MOTION DETECTION

7/87

DNA REMOTE SECURITY STATION



CANDIDATE SENSORS

TV/LLLTV
PASSIVE IR TELESCOPE
ACOUSTIC ARRAY
DIRECTIONAL MICROPHONE
LIGHT LEVEL
TEMPERATURE
HUMIDITY/RAIN
WIND
IR SPOTLIGHT
FLIR?
SEISMIC
MONOSTATIC MW MOTION
LASER RF
SHAD - (AC HELI DET)
GROUND SURVEILLANCE RADAR

PORTABLE (NON-MOBILE) TELEOPERATED SENSOR PLATFORM

7/87

ALARM PRIORITIZING - RSS

PRIORITY FACTOR	FACTOR SELECTOR	FACTOR THRESHOLD
WEATHER	SENSOR	MEASURED
THREAT ANALYSIS	SENSOR OR SITUATION	SELECTABLE
LOCATION OF ALARM	SITUATION	SELECTABLE (RANKED)
ALERT STATUS	SITUATION	SELECTABLE
OPERATIONS SCHEDULE	SITUATION	PROGRAMMABLE
RECENT HISTORY	SITUATION	PROGRAMMABLE

7/87

PRIORITIZING ALARMS BY RECENT HISTORY

- SENSOR MALFUNCTION RECORDS
- REAL-TIME INTRUSION SEQUENCE OF ALARMS

WEATHER EFFECTS ON SENSOR RANGE/SENSITIVITY

	LIGHT LEVEL	TEMP	HUMIDITY/RAIN	WIND
TV	SAME	--	INV/DA	--
ACOUSTIC ARRAY	--	--	INV/DA	INV/DA
DIR MIC	--	--	INV/DA	INV/DA
IR SCOPE	--	INV?	INV/DA	--
IR SPOTLIGHT	--	INV?	INV	--
1-D MOTION DETECTION	SAME W/O IR LITE	--	INV/DA	--
FLIR	--	INV?	INV/DA	--

INV = RANGE CHANGES INVERSELY WITH PARAMETER
DA = REDUCE PRIORITY OF ALARMS AS PARAMETER INCREASES UNTIL SOME THRESHOLD REACHED--THEN DISREGARD ALARMS.

PRIORITIZING ALARMS BY LOCATION OF ALARM

- PROXIMITY TO ASSETS/VALUE OF ASSETS
- PROXIMITY TO OTHER DETECTORS/PATROLS
- GEOGRAPHIC FEATURES
- VULNERABILITY

PRIORITIZING ALARMS BY THREAT ANALYSIS

- INTELLIGENCE INFORMATION
- ALARMED SENSOR STIMULUS
- OTHER ANALYSES

PRIORITIZING ALARMS BY OPERATIONS SCHEDULE

- DESENSITIZE AREAS OF ACTIVITY
  - MOVEMENT
  - NOISE
- SUBSTITUTE FOR DEACTIVATED SENSORS

PRIORITIZING ALARMS BY ALERT STATUS

- RANK PRIORITY OF LOCATIONS
  FOR EACH ALERT LEVEL
- DIFFERENT PRIORITIES AS
  PATROL/SURVEILLANCE CHANGES

Directionality from Passive Sensors

1. **TIME–DIFFERENCE–OF–ARRIVAL (TDOA)**

   Uses the cross–correlation matrix of the sensor signals to determine a bearing.

2. **BEAMFORMING**

   Time shifts the sensor signals to an assumed direction (called the look–angle) and adds the signals together. The resulting signal is called the beamformer output.

Assumptions

Target Type – Narrow and Broadband

Frequency of Interest – Below 200Hz

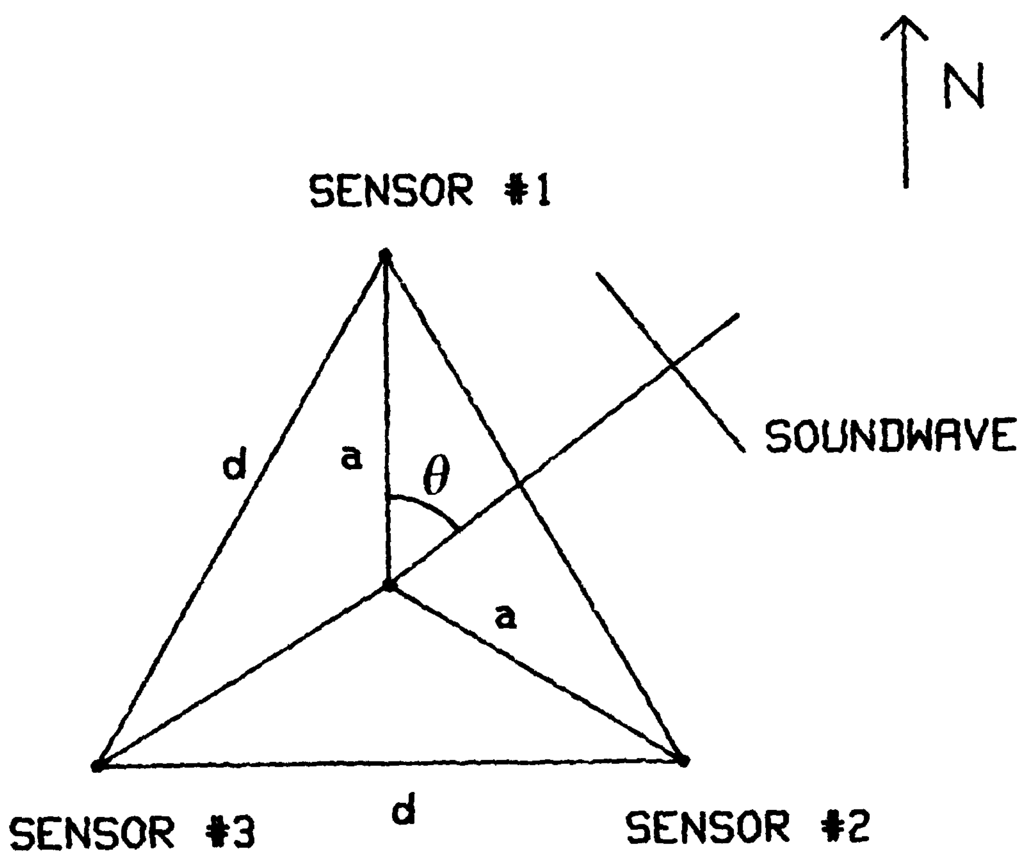
Number of Sensors – As few as possible (3)

Resolution Required – No worse than the field-of-view of a video camera (approximately 30°)

System Constraints Produce Conflicting Requirements

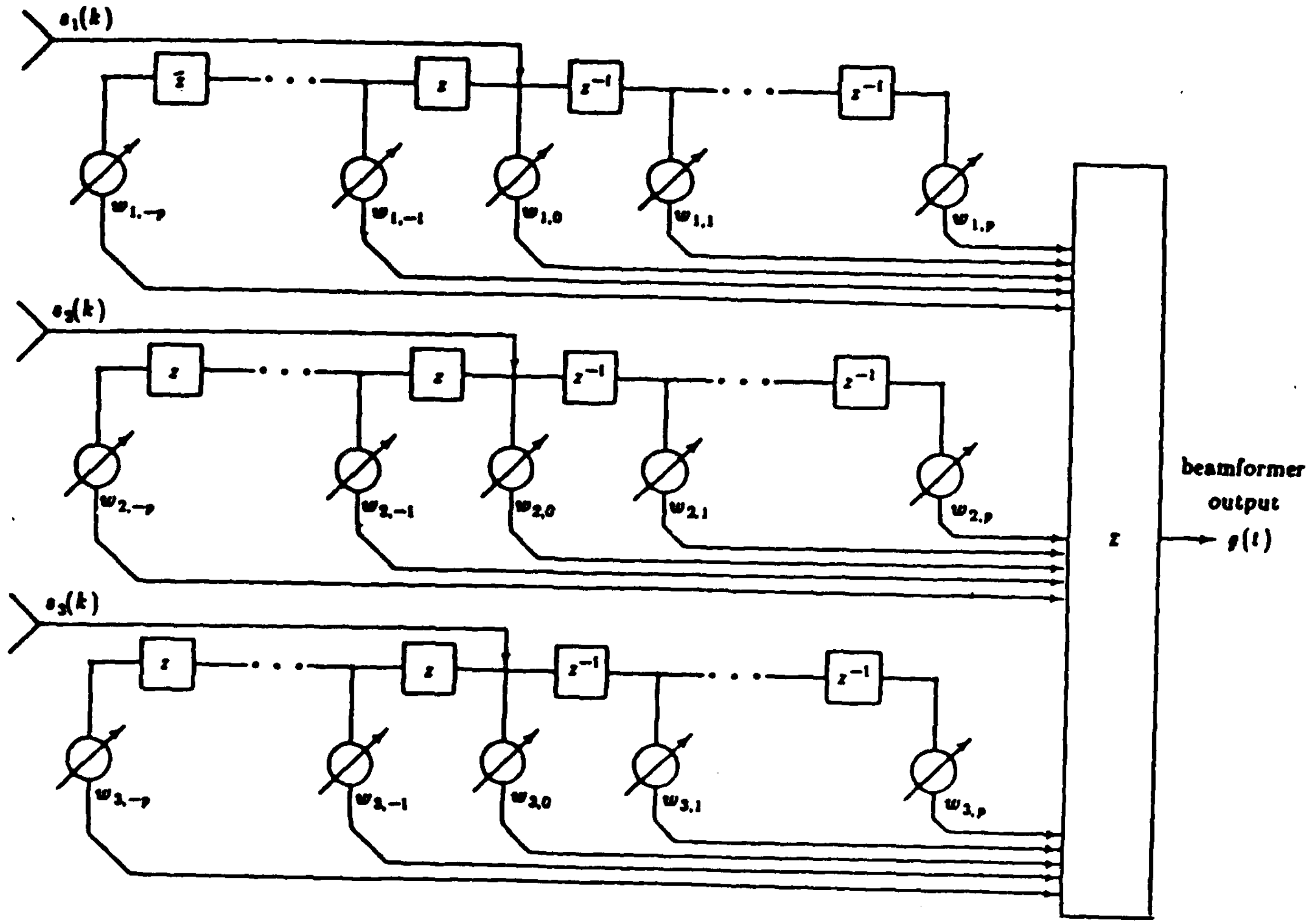
Small angular resolving power	$\Delta\theta \approx \frac{\lambda}{d}$ for a given λ increase d or for a given d decrease λ
Observe aliasing laws	$d < \frac{\lambda}{2} = \frac{V_{sound}}{2f_{max}}$ (Spatial)
	$f_s > 2f_{max}$ (Temporal)
Realizable, compact hardware implementation	Low f_s (for inline processing) Small d Few sensors

SENSOR LAYOUT

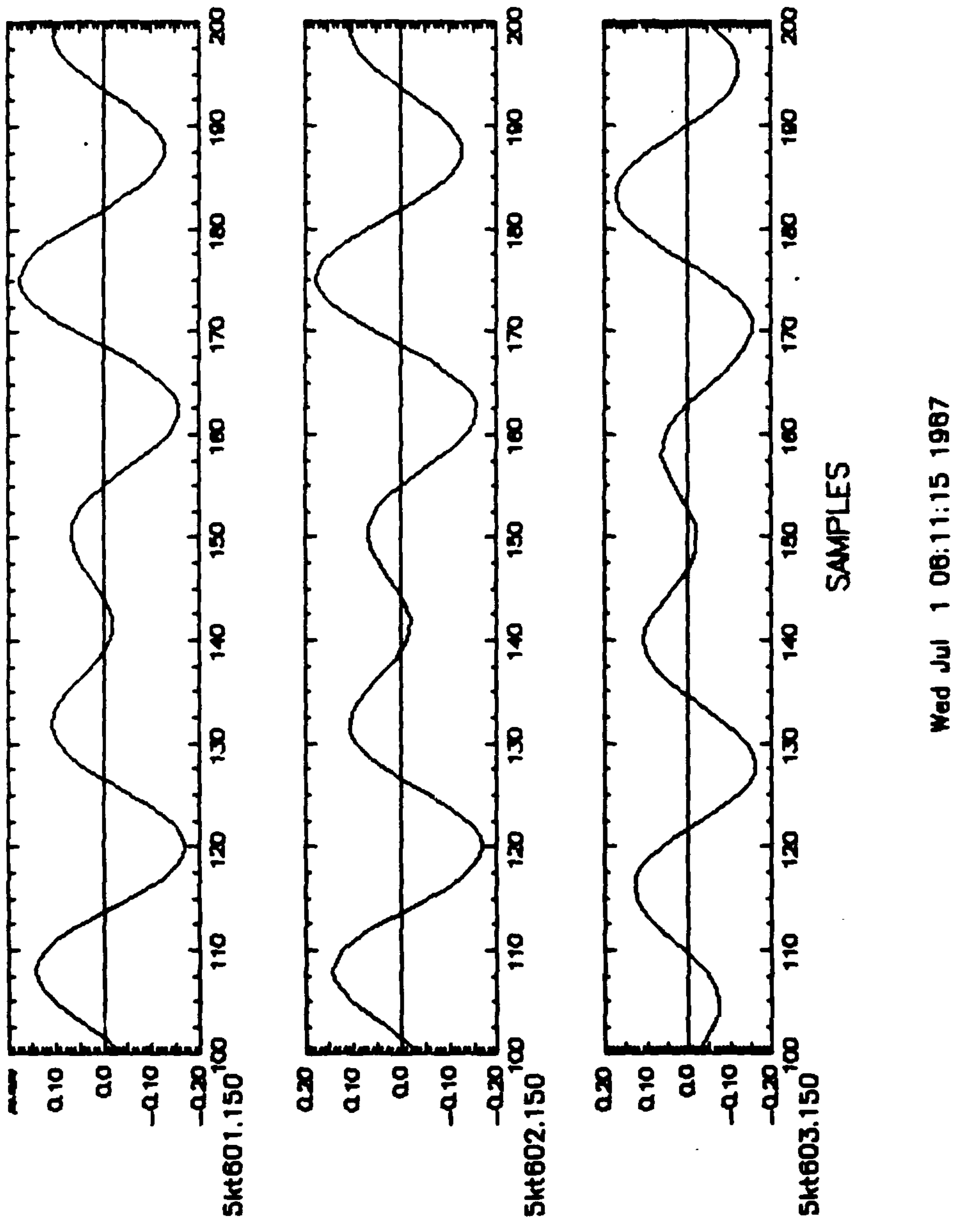


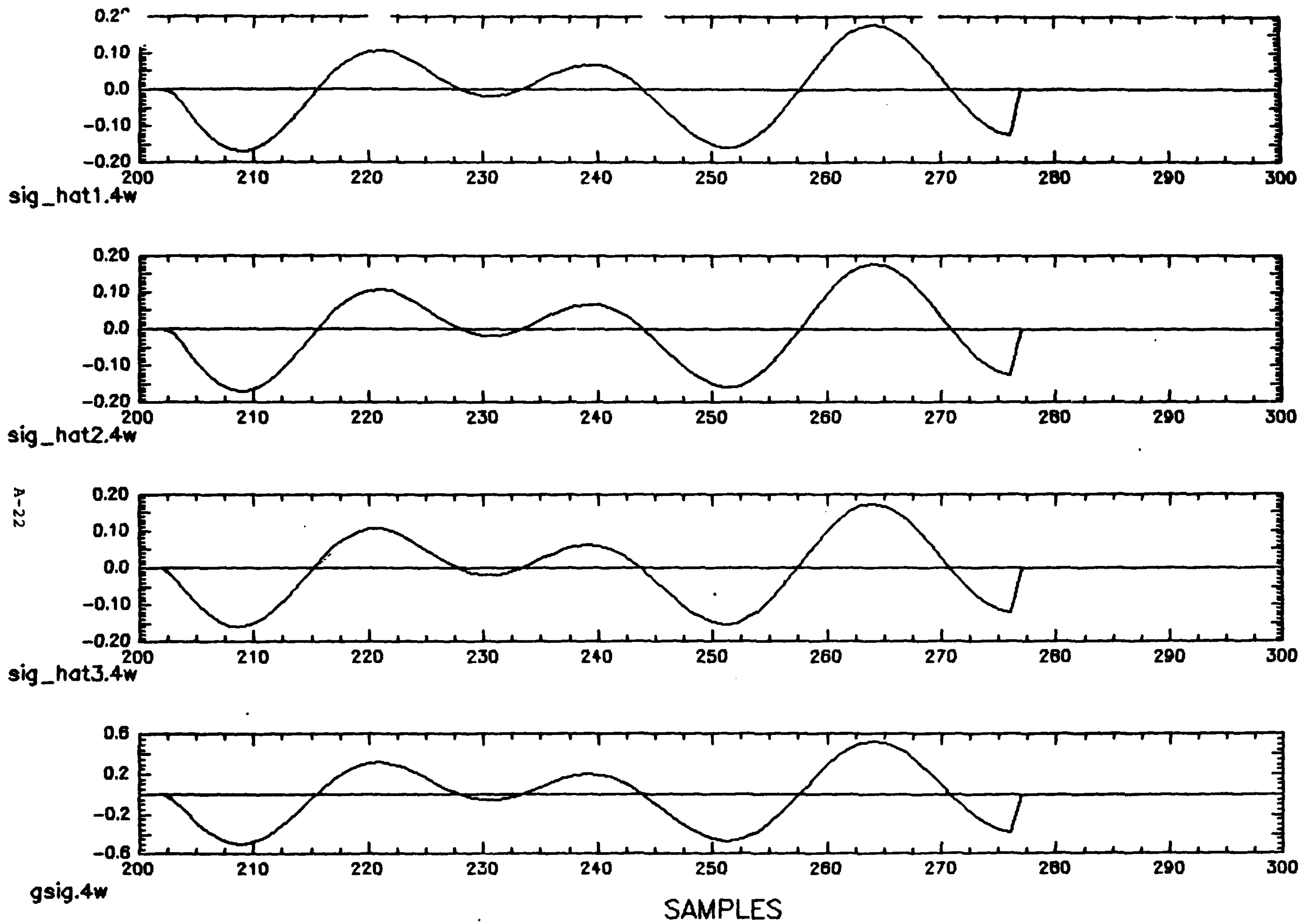
$$\tau_n = -\frac{a}{V_s}\,\mathrm{COS}((n-1)*120-\theta) \qquad d < \frac{\lambda}{2} = \frac{V_s}{2F_s}$$

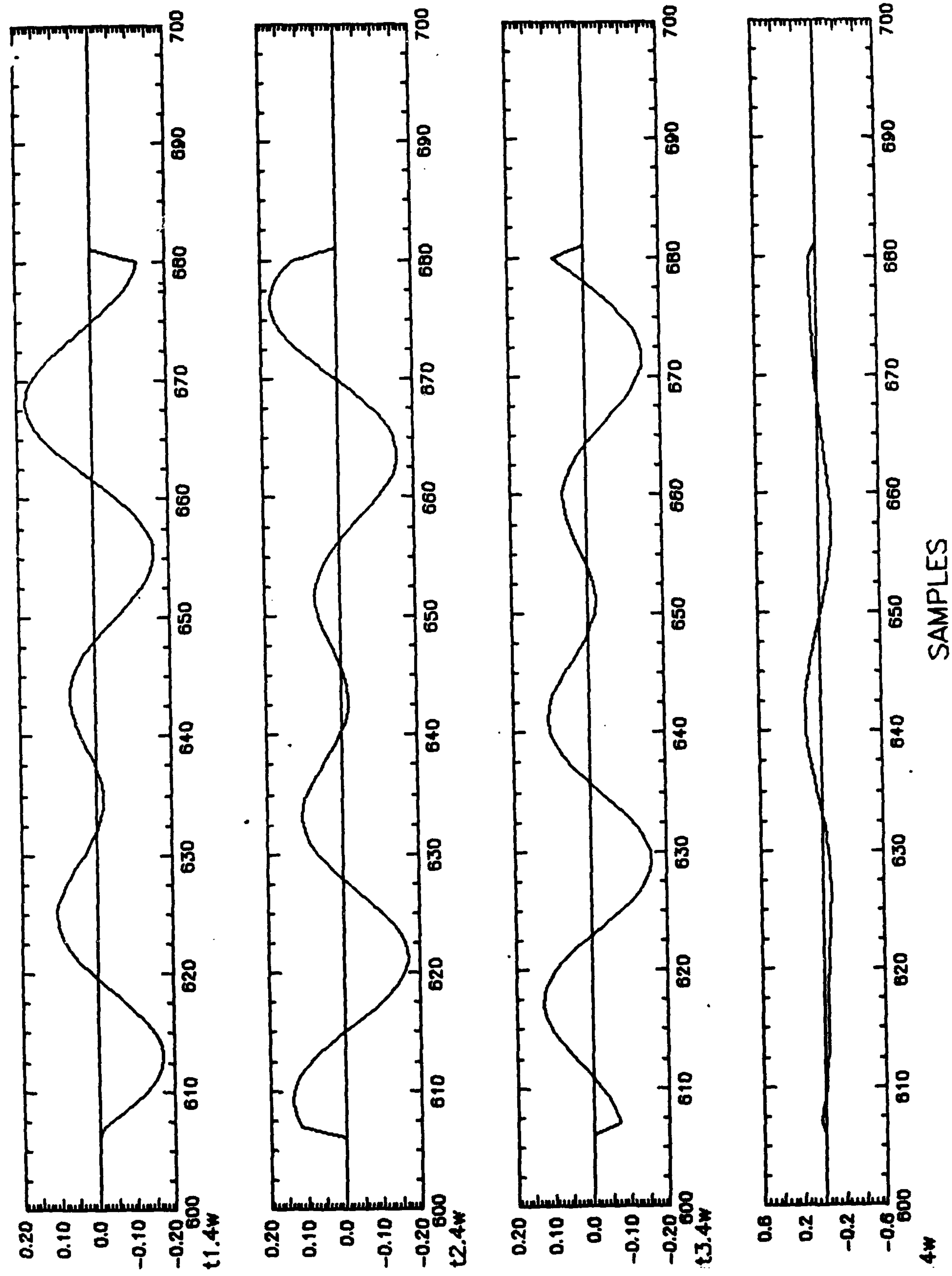
FOR n = 1,2,3



Three-channel beamformer with steering process for broadband signal

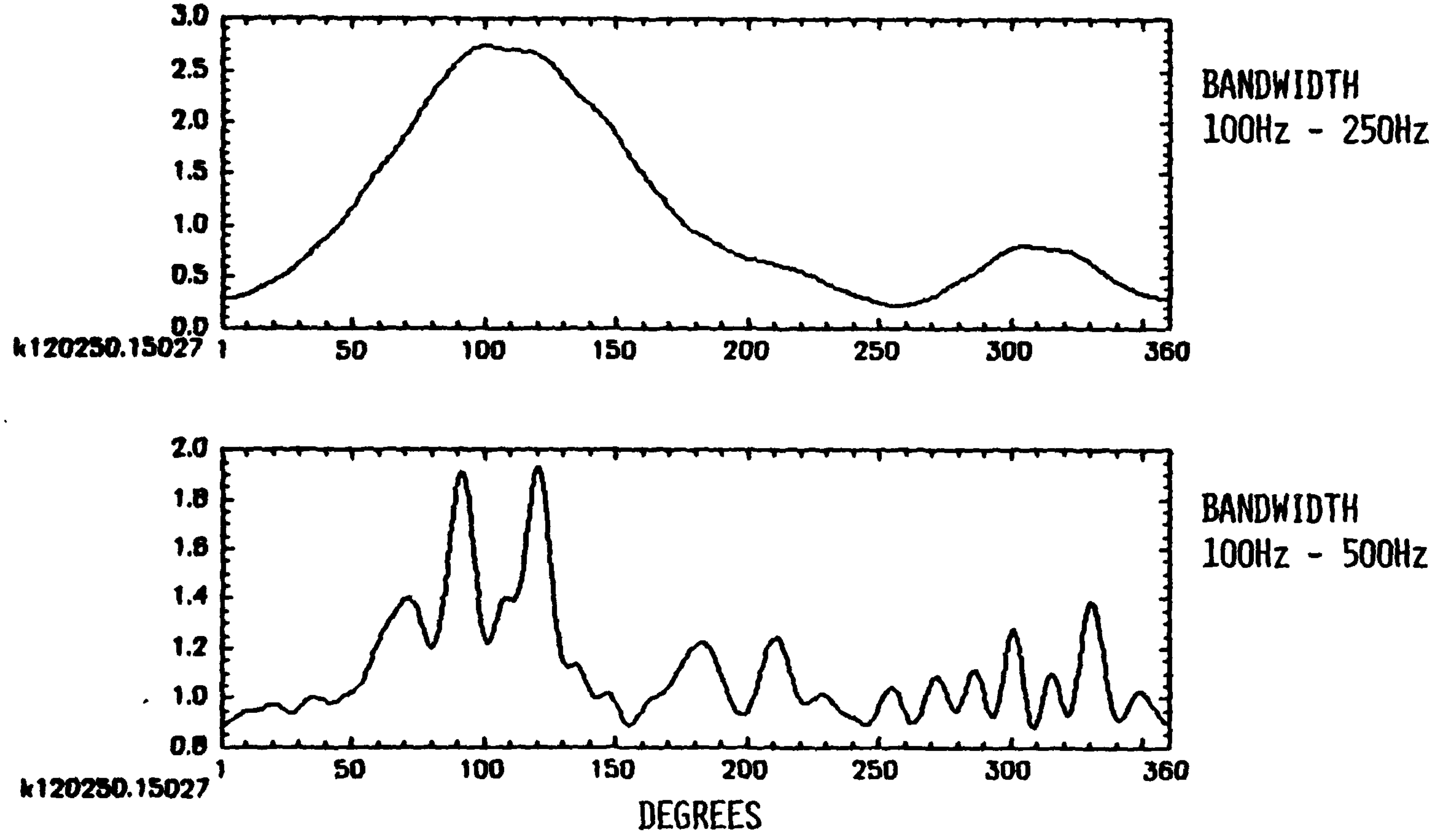

5kt601.150
5kt602.150
5kt603.150
0.10
0.0
-0.10
-0.20
0.20
100
110
120
130
140
150
160
170
180
190
200
SAMPLES
Wed Jul 1 08:11:15 1987


0.2
0.10
0.0
-0.10
-0.20
200 210 220 230 240 250 260 270 280 290 300
sig_hat1.4w
0.20
0.10
0.0
-0.10
-0.20
200 210 220 230 240 250 260 270 280 290 300
sig_hat2.4w
0.20
0.10
0.0
-0.10
-0.20
200 210 220 230 240 250 260 270 280 290 300
sig_hat3.4w
0.6
0.2
-0.2
-0.6
200 210 220 230 240 250 260 270 280 290 300
gsig.4w
SAMPLES


t1.4w
t2.4w
t3.4w
4w
SAMPLES
600
610
620
630
640
650
660
670
680
690
700
0.20
0.10
0.0
-0.10
-0.20
0.6
0.2
-0.2
-0.6

RATIO DETECTOR OUTPUT

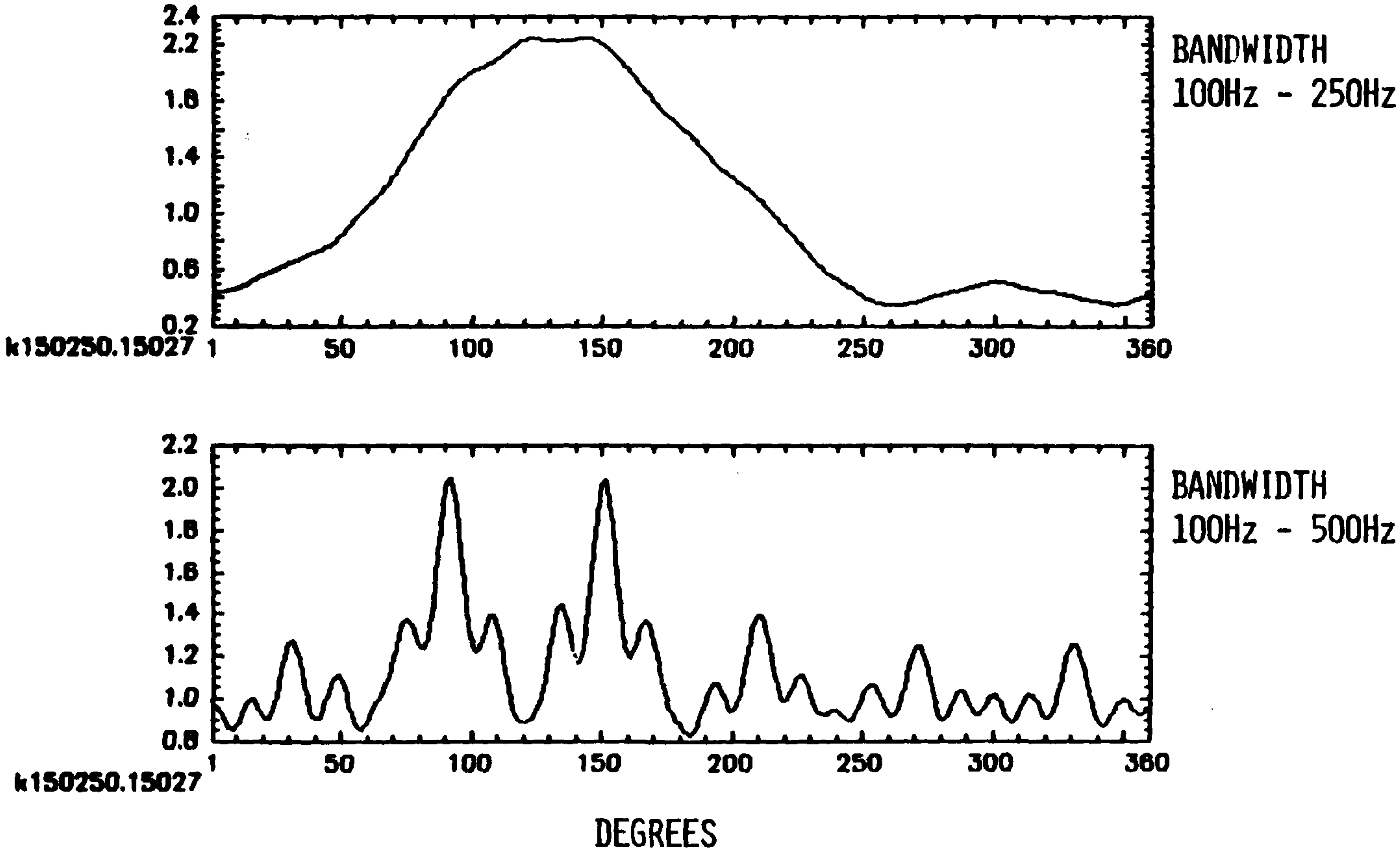
INPUT: BROADBAND NOISE
FS = 5KHz



Tue Jun 30 09:23:08 1987

RATIO DETECTOR OUTPUT

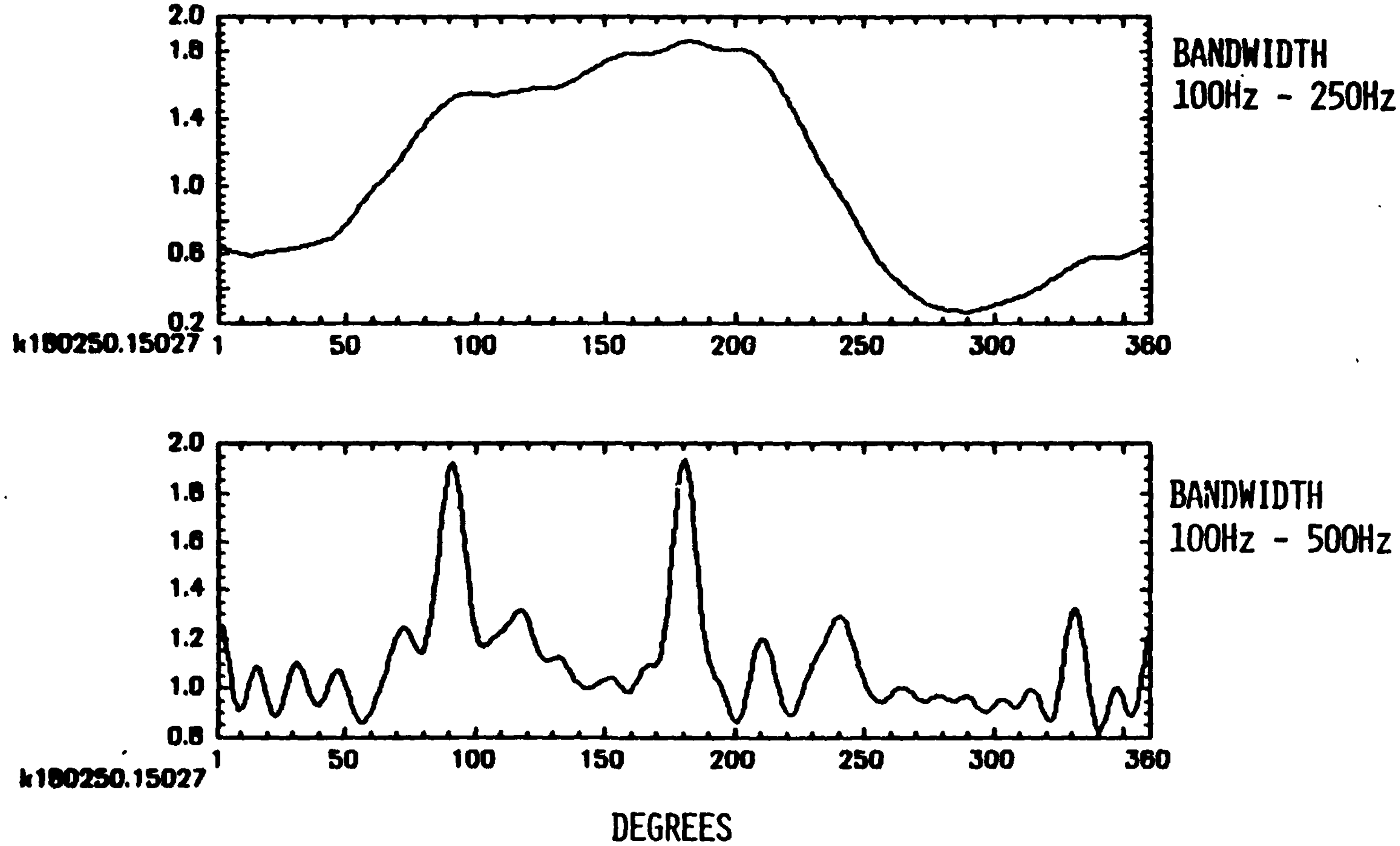
INPUT: BROADBAND NOISE
FS = 5KHz



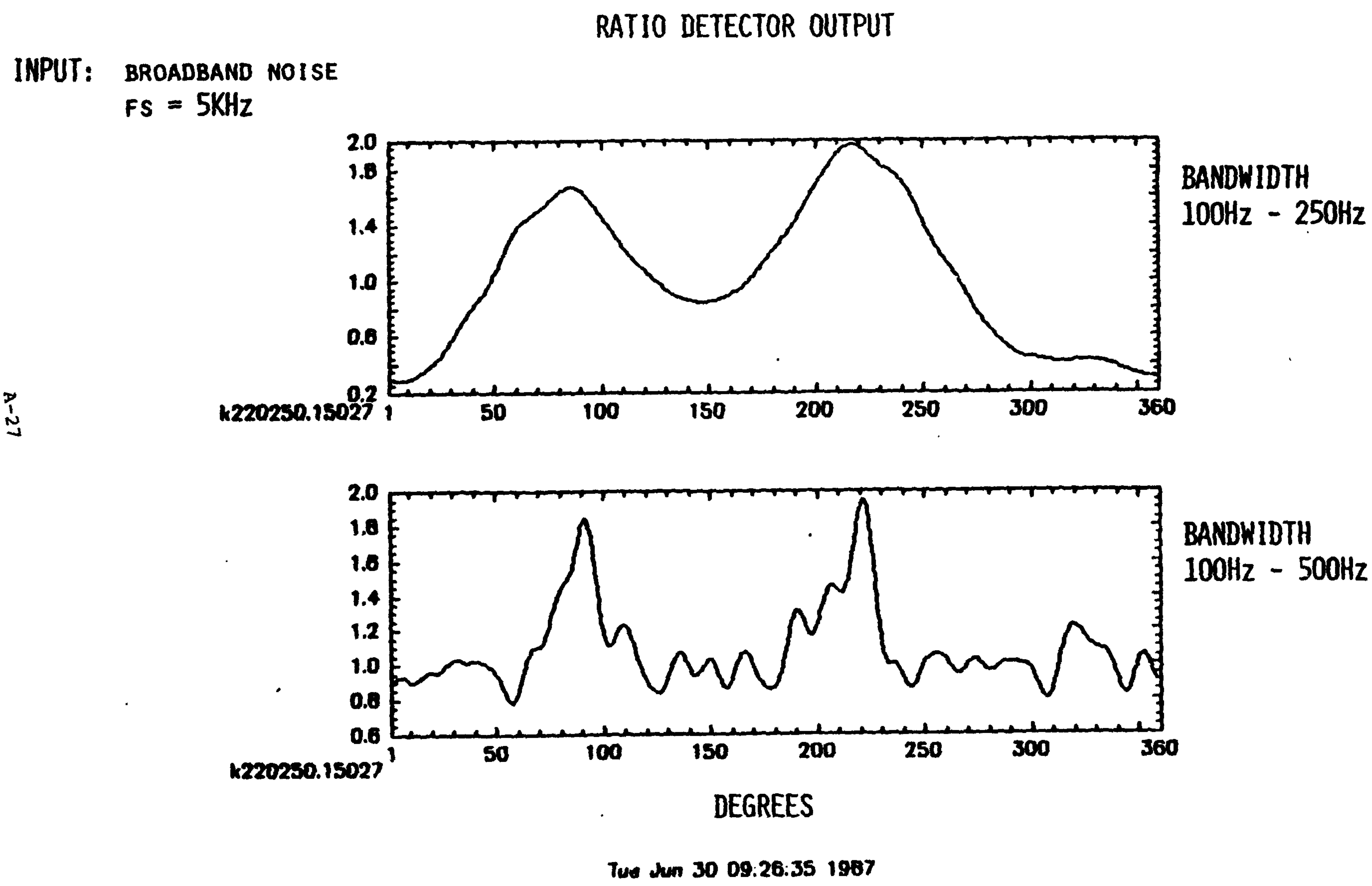
Tue Jun 30 09:25:43 1987

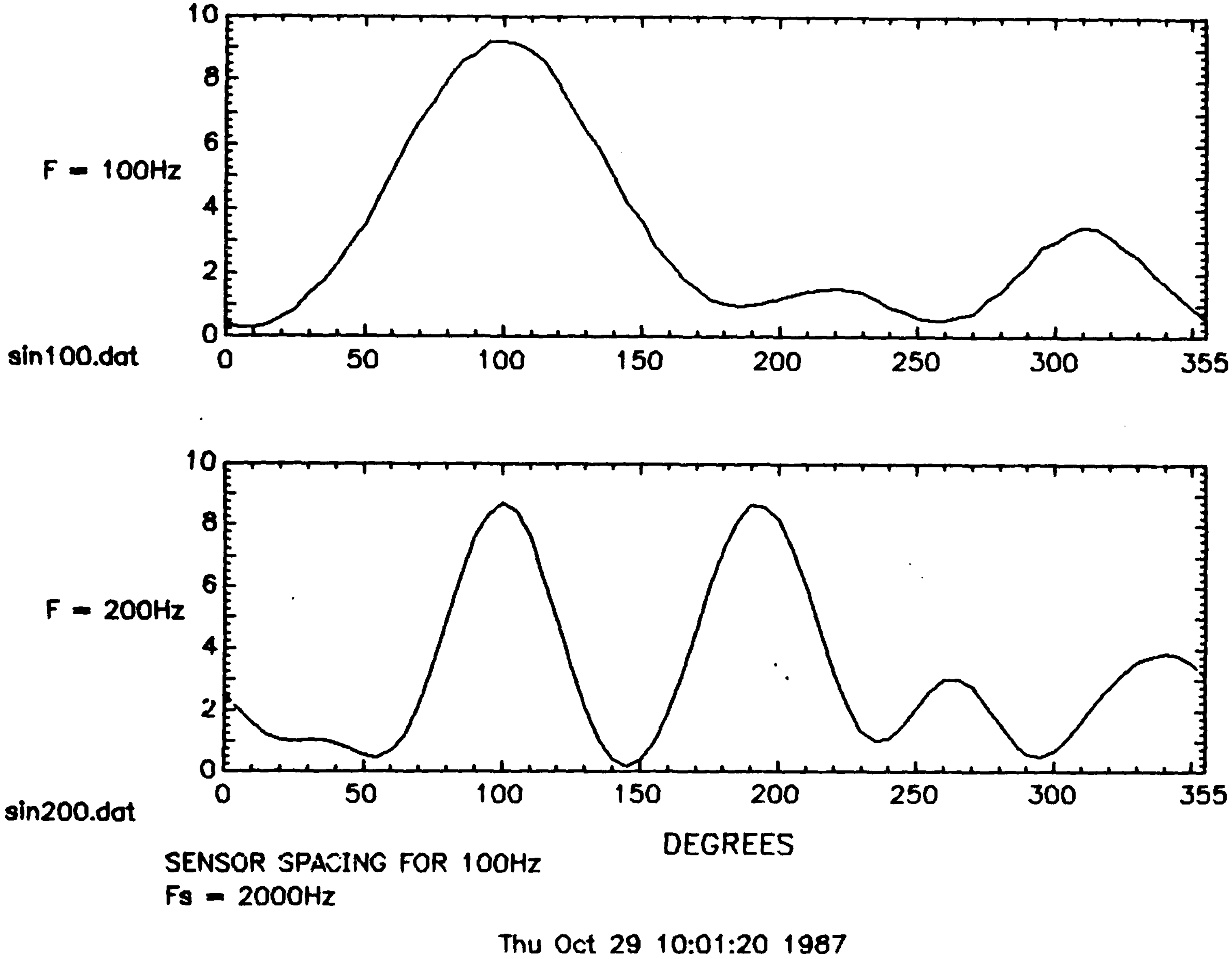
RATIO DETECTOR OUTPUT

INPUT: BROADBAND NOISE
FS = 5KHz



Tue Jun 30 09:24:06 1987


RATIO DETECTOR OUTPUT
INPUT: BROADBAND NOISE
FS = 5KHz
2.0
1.8
1.4
1.0
0.6
0.2
k220250.15027
1
50
100
150
200
250
300
360
BANDWIDTH
100Hz - 250Hz
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
k220250.15027
1
50
100
150
200
250
300
360
BANDWIDTH
100Hz - 500Hz
DEGREES
Tue Jun 30 09:26:35 1987


F = 100Hz
sin100.dat
F = 200Hz
sin200.dat
DEGREES
SENSOR SPACING FOR 100Hz
Fs = 2000Hz
Thu Oct 29 10:01:20 1987

THE BEARING ALGORITHM

1. CALCULATE THE BEAMFORMER OUTPUT USING NARROW–BAND DATA FOR LOOK–ANGLES OF 0 – 330DEG. , WITH A STEP SIZE OF 30DEG.

2. CALCULATE THE RATIO OF THE

$$\frac{\text{AVERAGE BEAMFORMER OUTPUT POWER AT EACH ANGLE}}{\text{AVERAGE POWER INCIDENT ON THE THREE MICROPHONES}}$$

3. EXAMINE THE RATIO FOR PEAKS.

4. CALCULATE THE BEAMFORMER OUTPUT, AND RATIO AGAIN USING WIDE–BAND DATA FROM THE SAME TARGET. BUT LIMIT THE LOOK–ANGLES TO A SMALL RANGE AROUND THE CENTER OF THE PEAK OR PEAKS FOUND IN 3. ALSO, DECREASE THE STEP SIZE FROM 30 DEG. TO 5 DEG.

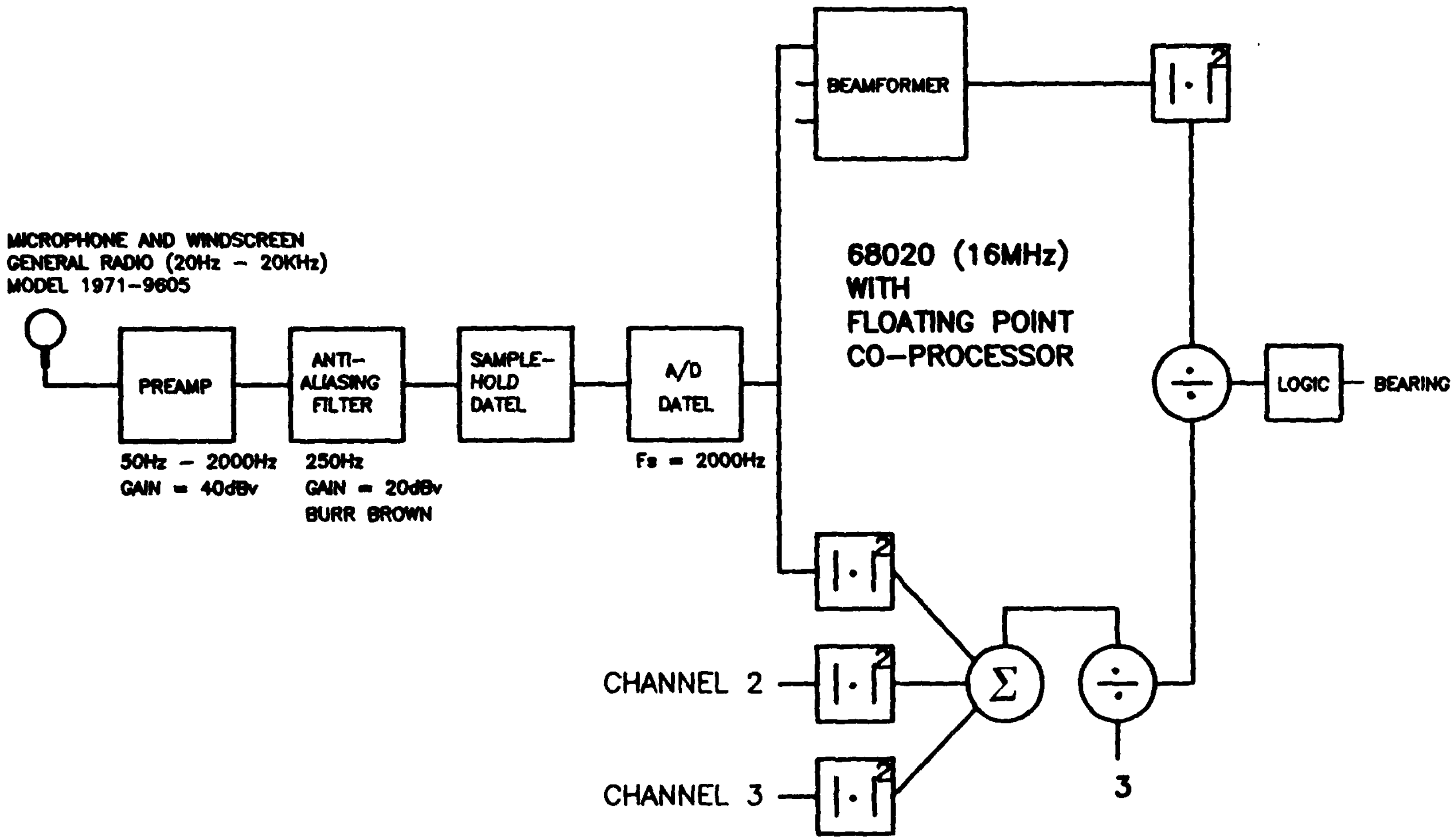
5. EXAMINE THE NEW RATIO FOR PEAKS.

6. DECLARE AN ALARM AND REPORT THE BEARING.

CURRENT PARAMETERS

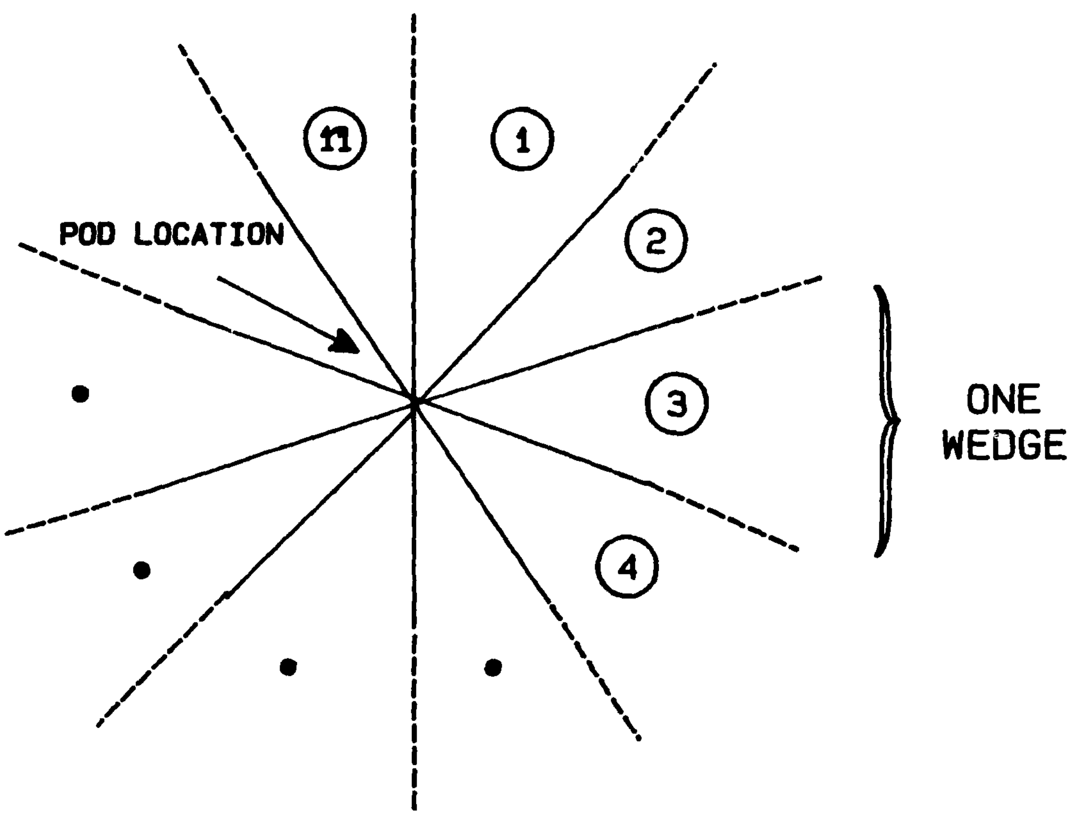
SENSOR SPACING (BASED ON SPECTRAL INFORMATION OBTAINED FOR DIFFERENT VEHICLES)	d = 1.46m (100Hz)
BANDWIDTH FOR NARROW–BAND BEAMFORMER	50Hz – 100Hz
BANDWIDTH FOR WIDE–BAND BEAMFORMER	50Hz – 150Hz
ACQUISITION TO ALARM TIME	~4sec

HARDWARE AND ALGORITHM BLOCK DIAGRAM



RSS SOFTWARE OVERVIEW

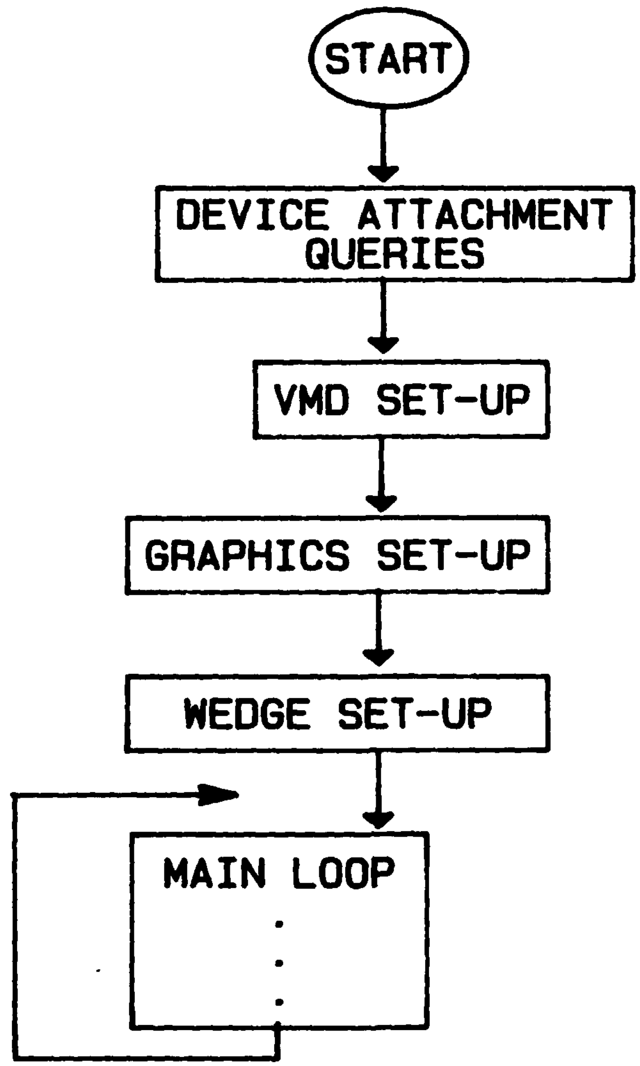
WEDGE DEFINITION



WEDGE ALARM THRESHOLDS RANGE FROM 0 TO 100 INCLUSIVE. SENSOR WEIGHTS ALSO RANGE FROM 0 TO 100, INCLUSIVE.

RSS SOFTWARE OVERVIEW

Program Flow Chart



RSS SOFTWARE OVERVIEW

OPERATOR ACTIONS

- ACTIONS THE INITIAL OPERATOR PERFORMS UPON INSTALLATION:
  - SET UP VMD BOXES
  - SET WEDGE THRESHOLD VALUES
  - DRAW AND SAVE MAP
- ACTIONS THE REGULAR OPERATOR MUST PERFORM UPON SUBSEQUENT START-UPS:
  - ANSWER DEVICE ATTACHMENT QUERIES
  - RECALL THE MAP, PLACE POD ICON
  - SET OR RECALL WEDGE THRESHOLD VALUES
- ACTIONS THE REGULAR OPERATOR MUST PERFORM WHEN PROGRAM IS RUNNING:
  - RESPOND TO ALARMS

RSS SOFTWARE OVERVIEW

DEVICE ATTACHMENT QUERIES

- OPERATOR TELLS PROGRAM WHICH OF THE FOLLOWING ARE ATTACHED:

  SEM
  GRAPHICS TABLET AND GRAPHICS MONITOR
  VMD
  ACOUSTIC ARRAY
  (SOUND)

RSS SOFTWARE OVERVIEW

GRAPHICS MENU SELECTIONS

DRAW OR MODIFY MAP

PLACE POD

ERASE SCREEN

RETRIEVE MAP FILE

ZOOM MAP

CURRENT CONDITIONS

TEMPERATURE	20 DEG C
HUMIDITY	46%
WIND	1 MPH
LIGHT	63
PIMS LEVEL	0

29 OCT. 1987
1725: 58

CONTROLS STATUS

OPERATION MODE	MAN
PAN (AREA)	0 (1)
TILT	0
POD MOVE	STOPPED
AUTOPAN	
VMDstat	RUNNING

EQUIPMENT STATUS

IR SCOPE	ON
VMD	ON
ACOUSTIC ARRAY	ON
IR LIGHT	OFF

ALARM STATUS

TIME	SENSOR	DIR	(AREA)	EVALUATION
1725: 54-	IR SCOPE	000	1	REAL
1725: 55-	VMD	000	1	ACKNOW
1725: 56-	ACOUSTIC ARRAY	235	7	UNACKNOW

OPTIONS

<CR>	MAIN MENU
<ALT-V>	TOGGLE VMD
'a'	ACKNOWLEDGE
'c'	CLEAR ASSESSED
'u', 'n', 'r'	ASSESSMENTS
<ALT-A>	TOGGLE ENVISION
'-'	ZOOM SPOTLIGHT
'+'	ZOOM SPOTLIGHT
<ALT-F1>	EXIT PROGRAM!

RSS SOFTWARE OVERVIEW

OPTIONS AVAILABLE IN MAIN LOOP

MENU

PAN AND TILT CONTROL

IR SPOTLIGHT ZOOM CONTROL

VMD TOGGLE

ENVISION ALPHANUMERIC TOGGLE

ALARM ACKNOWLEDGMENT

ALARM ASSESSMENT

TOGGLES (MENU ITEM)

ALARM HISTORY (MENU ITEM)

PROGRAM TERMINATION

RSS SOFTWARE OVERVIEW

MENU CHOICES

TOGGLES

ALARM HISTORY

TEXT LOG

WEDGE INFO

WEDGE THRESHOLD ADJUSTMENT

GRAPHICS FUNCTIONS

ENVIRONMENTAL DATA

SENSOR STATISTICS

RSS SOFTWARE OVERVIEW

MAIN LOOP

- GET ENVIRONMENTAL DATA
- UPDATE SCREEN
- POLL SENSORS FOR RAW ALARMS
- IF THERE ARE ANY RAW ALARMS,
  - ADJUST SENSOR WEIGHTS
  - EVALUATE RAW ALARMS,
    - GENERATE TRUE ALARMS
  - IF THERE ARE ANY TRUE ALARMS,
    - NOTIFY HUMAN OPERATOR*
- STROBE KEYBOARD
- IF AN OPTION KEY IS PRESSED, *
  - CARRY OUT OPTION
- SEND PAN AND TILT COMMANDS, IF ANY.

*The only places where there is program-operator interaction.

RSS SOFTWARE OVERVIEW

ALARM GENERATION

- POLL SENSORS FOR RAW ALARMS.
- IF THERE ARE ANY RAW ALARMS,
  - ADJUST SENSOR WEIGHTS ACCORDING TO ENVIRONMENTAL HISTORY AND SENSOR ALARM HISTORY.
  - FOR EACH WEDGE WITH ALARMS IN IT,

    SUM THE WEIGHTS OF THE SENSORS THAT ALARMED IN THIS WEDGE.

    IF THIS SUM EXCEEDS THE WEDGE ALARM THRESHOLD,

    GENERATE A TRUE ALARM

    NOTIFY THE HUMAN OPERATOR*

*The only place there is program-operator interaction

RSS SOFTWARE OVERVIEW

OPERATOR ACTIONS TO HANDLE AN ALARM

ACKNOWLEDGE ALARM

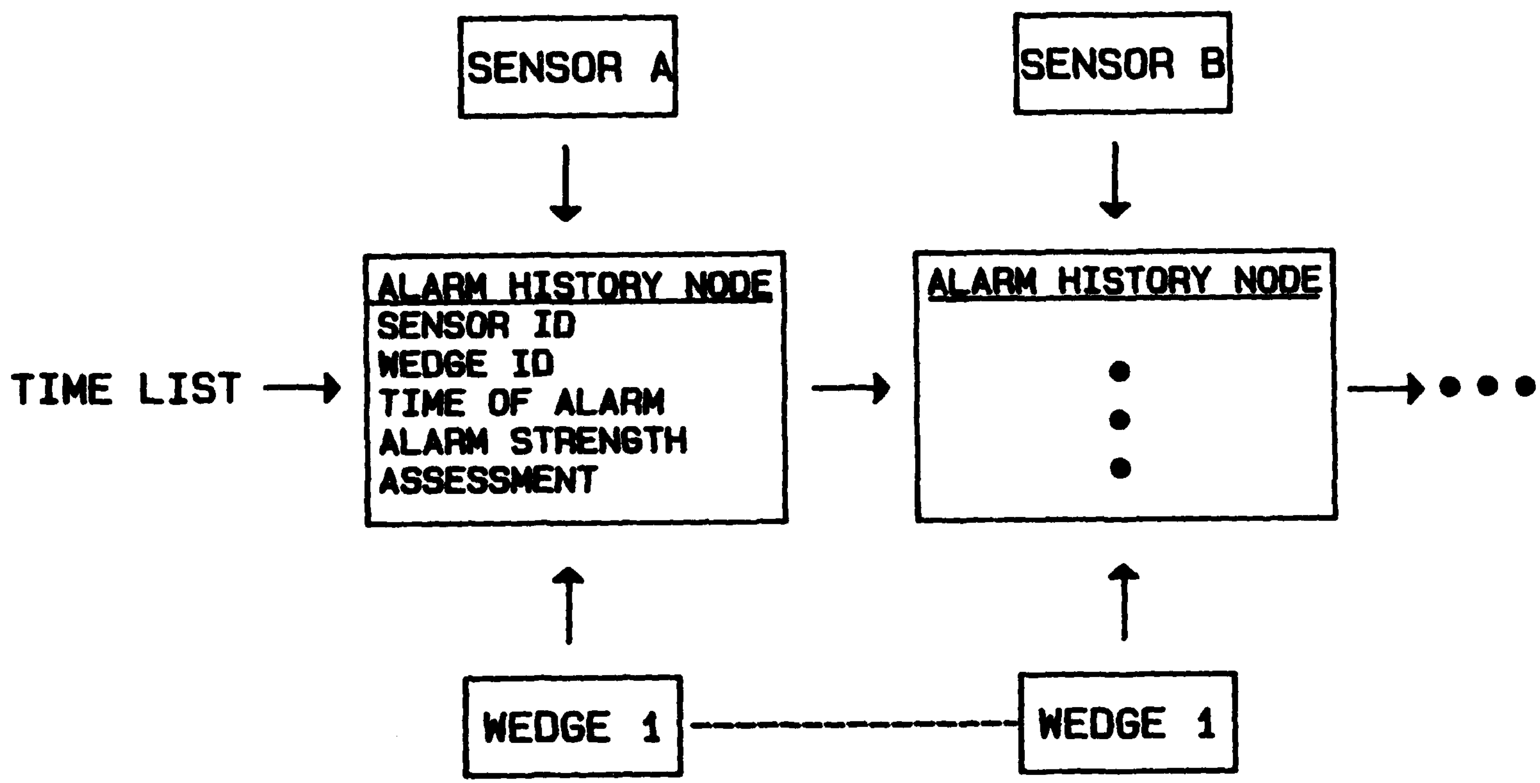
TURN POD TO ALARM BEARING*

ASSESS ALARM

*MAY BE HANDLED AUTONOMOUSLY

RSS SOFTWARE OVERVIEW

ALARM HISTORY STORAGE



APPENDIX B

ACOUSTIC DETECTION SYSTEM

Lonnie A. Hayden
Sandia National Laboratories
Albuquerque, New Mexico 87185-5800

SENSOR BEARING ALGORITHMS

There are many similar algorithms which can be used to determine the bearing of an acoustic target. One common method is based on the difference between the Times-of-Arrival (TOA) of a far field signal as it is received by several sensors positioned at known locations in space. The calculations needed to determine the TOA of the signals involves finding the cross-correlation of the different sensor signals. Once the cross-correlation of the signals has been determined, the delays between the TOA of the different sensor signals can be found by examining the cross-correlation function for peaks. It is the delay between the sensor signals that is used to determine the bearing of the acoustic target. There are some drawbacks to using this type of algorithm. The first is that a large number of calculations are needed to determine all the cross-correlation functions. A second drawback, which is inherent in the calculation of discrete cross-correlation functions, is that only discrete values for the delays can be obtained (i.e., if the actual delay between two signals was 4.4 samples, the discrete delay would be 4.0 samples). This results in an inaccurate estimate of the bearing. There are ways to increase the accuracy of the cross-correlation algorithm, but they involve adding more sensors. This, then, increases the number of computations needed to calculate the cross-correlation functions. Also, this method does not work well when multiple target signals are present in the sensor signals. There are methods using the cross-correlation matrix for large arrays of sensors that can handle multiple targets. However, these methods require very powerful computers to handle the computations in any reasonable amount of time.

BEAMFORMING ALGORITHM

Beamforming is in many ways similar to cross-correlation, but differs in one important way. Instead of using the cross-correlation function to calculate the delays, beam-forming assumes that the acoustic source of interest is located at a specific point in space (the horizontal angle to the assumed point in space is called the look-angle). The beamforming algorithm then calculates the delays that would occur if the source was actually located at the assumed point in space. Using these delays, the algorithm shifts the sensor signals by an amount opposite, but equal to, the calculated delays. These shifted signals are then added together with the combined signal being called the beamformer output. Therefore, the beamformer output will amplify the signal of a target when it is located in the direction of the look-angle, and cancels the signal of a target when it is not in the direction of the look-angle. The beamforming algorithm uses the common sinc function to preform the shifting of the signals. The use of the sinc function allows the algorithm to shift the signals by any amount of delay. This is in direct contrast to the cross-correlation algorithm which can only determine the delay to the nearest discrete value.

BEARING ALGORITHM

The initial algorithm used with the DNA Remote Security Station is a spin-off of the beamforming algorithm. This algorithm involves three microphones which are

equally spaced around the circumference of a circle. The microphones are located a distance d from each other. The distance d between the microphones is determined by the following equation,

$$d < \text{lambda} / 2 = v / 2*fh,$$

where lambda is the wave-length of the highest frequency of interest, v is the speed of sound, and fh is the highest frequency of interest. This distance is used so that 180 degree ambiguities do not occur in the beamformer output. These ambiguities are commonly referred to as spatial aliasing. After sampling the three microphone signals (which at this point are band-limited so that spatial aliasing does not occur), the algorithm time shifts the microphone data for twelve different look-angles. These angles range from 0-330 degrees, with a step-size of 30 degrees. The 30 degree step-size is used to increase the speed of the algorithm, and produces satisfactory results. The time-shifted signals are then added together. The average power of the beamformer output is then divided by the average power of the three microphone signals. This ratio is an indication of the amount of acoustic power in the look direction, compared to the total acoustic power incident on the three microphones. The algorithm then compares this ratio data to a predetermined threshold. If the ratio data exceeds this threshold, then a directional noise source is present. The algorithm then determines the rough bearing of the noise source by searching for the largest value in the ratio data. This will give a bearing which is within approximately $\pm$ 15 degrees of the target. After determining the rough bearing, the algorithm then computes the beamformer output and ratio for look-angles on either side of the rough bearing. Only this time, the data used for these calculations has a wider bandwidth. This wide-band data is used in order to improve the resolving power of the three microphone array. It is important to note that using high frequency data as a means of improving the resolving power of the microphone array must be done with care as spatial aliasing can occur. However, because the algorithm calculates the beamformer output and ratio over a small range around the rough bearing (in which spatial aliasing cannot occur), the effects of spatial aliasing should pose no problem. Also, the look-angle is varied in five degree increments (which should give the needed resolution to point a camera at a far field target). A block diagram of the algorithm is shown in Figure 1.

PROPOSED HARDWARE

The hardware used to run the target detection algorithm is based on a VME system with a 68020 micro-processor and math co-processor. The data acquisition system portion of the hardware consists of the following: 1) a microphone preamp (see Figure 2); 2) an analog line amplifier; 3) an anti-aliasing filter; 4) a sample-and-hold: and 5) a 12 bit analog-to-digital converter. A block diagram of the hardware is shown in Figure 3.

SYSTEM LIMITATIONS

There are three major limitations which will effect the performance of the acoustic bearing algorithm. These limitations are: 1) range, 2) tracking ability, and 3) bearing accuracy.

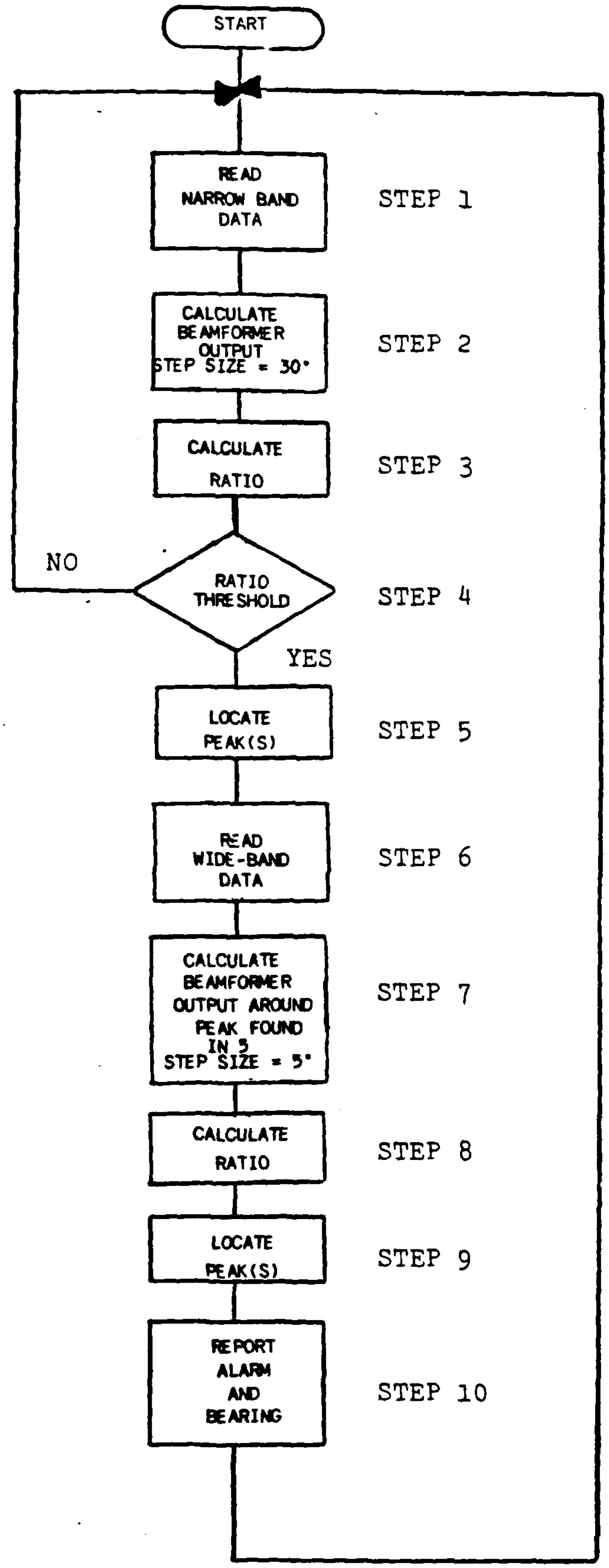
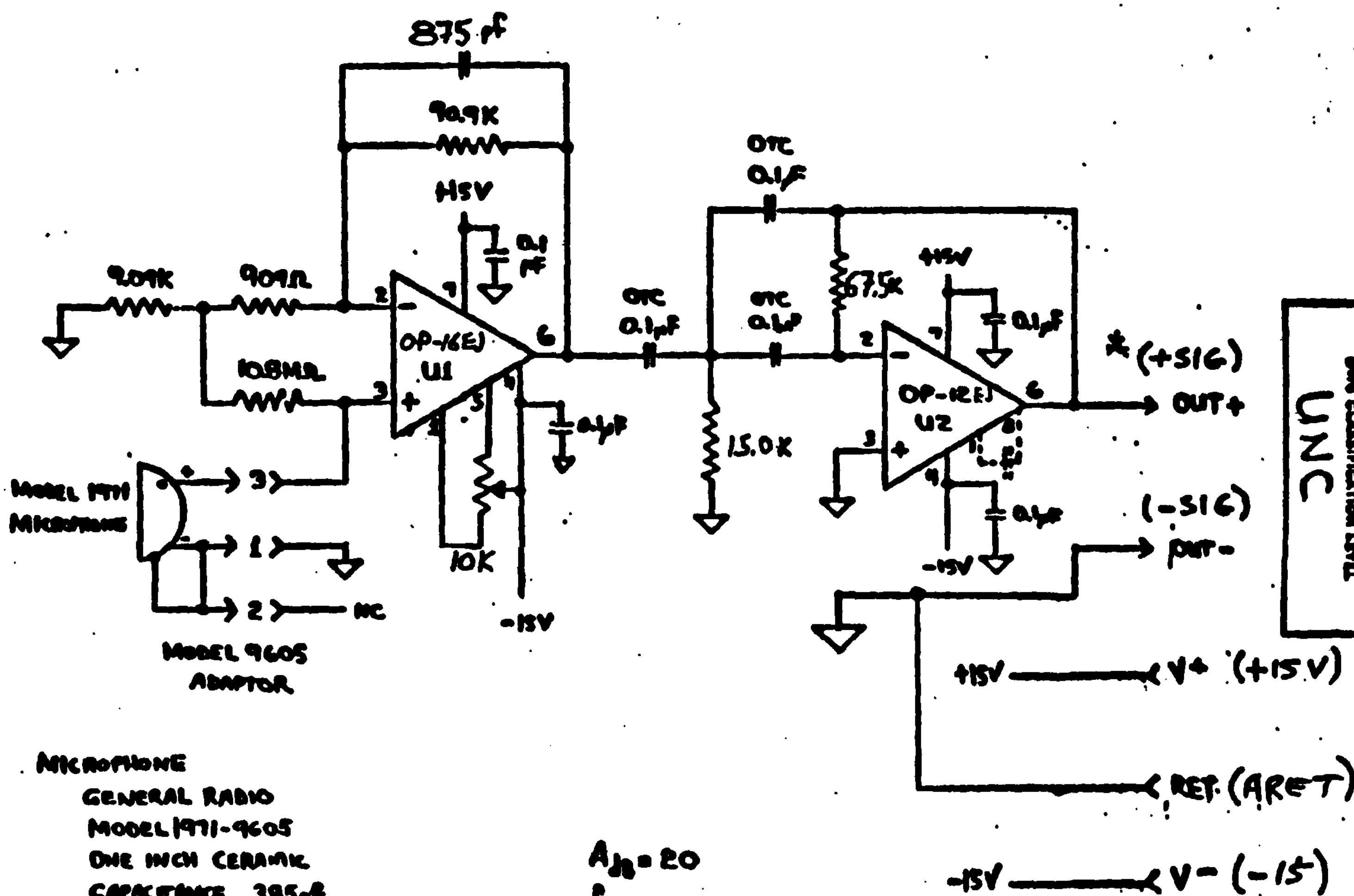


FIGURE 1. General Block Diagram of the Proposed Algorithm

FIGURE 2.



MICROPHONE
GENERAL RADIO
MODEL 1971-9605
ONE INCH CERAMIC
CAPACITANCE 385pF
SENSITIVITY -40dB re 1V/N/m²
(-60dB re 1V/μbar)
MODEL 1971-9605 COMES
WITH ADAPTOR TO STANDARD
3-PIN AUDIO CONNECTOR

$A_{dB} = 20$
$f_{LP} = 2000Hz$
$f_{HP} = 50Hz$

* ( ) ARE FUNCTIONAL BLOCK LABELS

DWG CLASSIFICATION LEVEL
UNC

REVISIONS

ISSUE	DESCRIPTION	DATE

APPROVALS

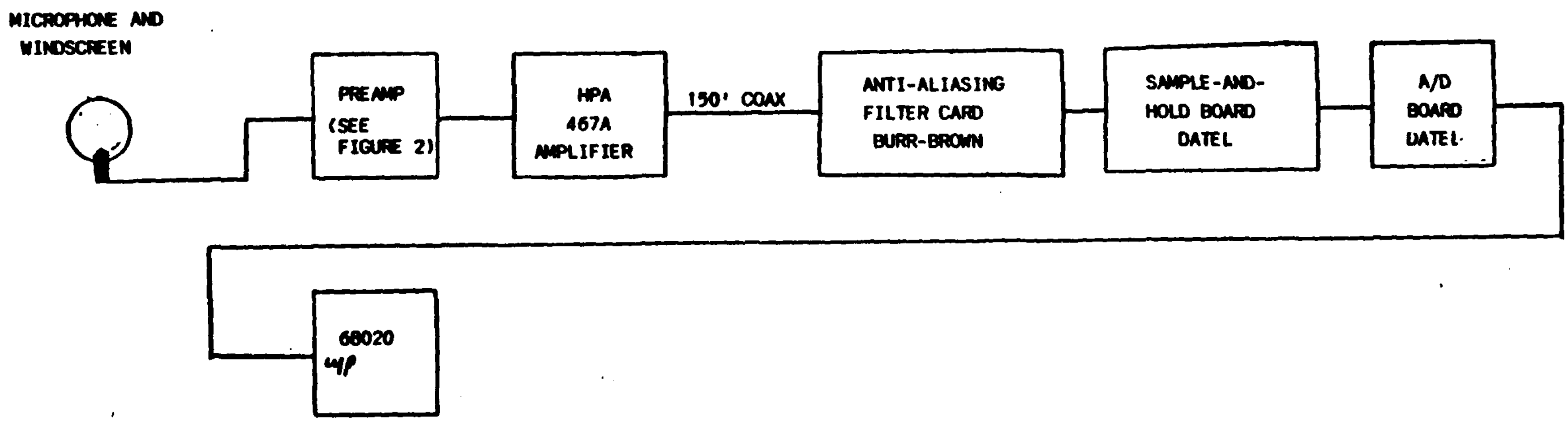
DWG	DATE	INITIALS
9238	1/11/83	RJF
5238	7/2/83	LAH

PART CLASSIFICATION
UNC

DWG CLASSIFICATION LEVEL
UNC

TITLE
MICROPHONE PREAMPLIFIER

SIZE A
DWG NUMBER
SCALE
SHEET 1 OF 1



*NOTE: THIS IS ONE OF THREE CHANNELS

FIGURE 3. Block Diagram of the Proposed Hardware

Range Limitations: The most dominant limitation of any acoustic system is its ability to "hear" the target of interest. The range at which the target can be heard is limited by three major factors. These factors are: 1) the amount of acoustic energy emitted, 2) the sensitivity of the sensors used to detect the acoustic energy, and 3) the amount of background noise present (both acoustic and system). If the target of interest is a jet, which radiates large amounts of acoustic energy, then detection ranges on the order of 15-20Km are quite realistic. If the target is a helicopter, reliable detection ranges on the order of 5-10Km would probably be possible. However, for typical land vehicles (which do not emit large amounts of acoustic energy), detection ranges on the order of 100-700m could be expected. Longer detection ranges would be possible if the vehicles of interest were tanks, trains, large trucks, and other large vehicles. Unfortunately, the average passenger vehicle is very quiet. The amount of acoustic energy emitted by these types of vehicles is very low, especially when moving at slow speeds. Therefore, the detection range of passenger vehicles will probably be between 100m and 300m on a paved road. The detection range would probably increase if the vehicle was traveling on a dirt road or off the road. The reason for this increase is due to the increase in road noise associated with traveling on dirt roads, and the increased engine noise associated with off-the-road travel.

Tracking Limitation: The limitation in range leads to another important limitation. After the current algorithm detects the presence of an acoustic source, it then tracks this source, giving new bearing information every 1.25 seconds (assuming the sound level of the source persists). The algorithm scans bearings ranging from +/-15 degrees from the last known bearing. If the target moves more than 15 degrees in the amount of time it takes to update the bearing estimate, the target cannot be tracked. To place this in perspective, a few examples are in order. Assume that a sound source is traveling in a circle around the center of the microphone array. If the radius from the center of the microphones to the source is 100m, then the maximum speed that the source could have around the circle is 0.2094 rad/sec (15deg/1.25sec) which at 100m corresponds to a speed of 20.94m/sec (or 46.85 mph). This is the theoretical maximum speed of a sound source at 100m that the algorithm could track. Of course, as the radius increases, so does the maximum speed at which the sound source can travel assuming a circular path. At a radius of 500m, for example, the sound source could move at a speed of 105m/sec (or 234 mph) and still be tracked. Obviously, this restriction does not apply if the sound source is moving towards the microphone array. In this case, the angular velocity is small.

Bearing Estimate Accuracy Limitations: The estimated bearing accuracy is probably the least significant of the overall system limitations. The bearing estimates for strong acoustic sources are generally not more then +/-5 degrees off. In fact, the error is usually zero degrees, keeping in mind that by design the algorithms bearing estimates are in increments of five degrees. Also, the acoustic source used to obtain these estimates was static. Of course, the accuracy of the bearing estimate is affected by background noise as well as atmospheric conditions. Wind is probably the most detrimental of all the atmospheric conditions. Wind is a source of background noise and also causes errors to occur in the bearing estimate. For example, a 10m/s (22.3mph) wind which is perpendicular to the target bearing will result in a bearing error of approximately 2 degrees (see [2]). Another factor that will effect the bearing

estimate is the time-of-flight of the sound waves emitted by an acoustic source. Sound waves travel at approximately 345m/seconds. Therefore, sound emitted from a source 1km from the microphone array takes 2.9 seconds to reach the microphones. For example, if an acoustic source is traveling at 100m/sec (224 mph) in a circle around the microphone array, and the distance to the source is 1km, the source will move 290m in the time it takes the sound waves to reach the microphones. This translates into a change in bearing of about 2.6 degrees. This however, will not be a problem if the target is moving toward the microphone array, or if the speed of the target is not too great. All of these sources of error combined should not cause a significant problem if queuing a TV camera is all that is required of the system.

APPENDIX C

A WEIGHTING/THRESHOLD APPROACH TO SENSOR FUSION

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SAND88-0094

Unlimited Release

A WEIGHTING/THRESHOLD APPROACH TO SENSOR FUSION

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ABSTRACT

A weighting/threshold-based sensor fusion algorithm to decrease the false alarm rate (FAR) while maintaining a high probability of detection (PD) is being tested in the Remote Security Station (RSS). The RSS is being developed to provide temporary intrusion-detection capability on short notice. It consists of a portable, multisensor pod connected by cable to a manned control console. The pod is set up outdoors in the location that security is needed; the console and operator are located in a command bunker up to a kilometer away. The RSS software filters out alarms from low-believability sensors and also filters out alarms in low-priority areas. Each sensor's believability is proportionally encoded as a weighting, which is continually updated as a function of the environmental conditions affecting that sensor. Area priority is proportionally encoded as a threshold value for each pie-wedge area around the pod. When an event in an area triggers one or more sensors, their weightings are summed and then compared to the area threshold value. The operator is informed of the event only if the summed weighting exceeds the threshold. Extensive field testing has not yet been done, but some results show the current sensor fusion algorithm decreases the FAR at the expense of lowering the PD. To increase the PD while retaining a low FAR, the weighting/ threshold algorithm will be modified to use temporal data and pattern recognition.

1.0 Introduction

The Remote Security Station (RSS) is designed to provide temporary intrusion detection capability on short notice. It is most suitable for replacing or augmenting a defective portion of the perimeter security system of a fixed site, although it may also be used at other sites such as new airfields or stopped vehicle convoys. The RSS reduces manpower requirements since only a single operator at the console is needed to run the RSS. The RSS sensor pod may be deployed in areas or under conditions where it would be undesirable to station a man, and it reduces operator workload by filtering out some false alarms. Sensor fusion is used in the RSS to perform this filtering, to determine the "truthfulness" of intrusion detection sensors when they trigger.

2.0 Terminology

In the following discussions, two kinds of sensors will be referred to. The first is the intrusion detection sensor which triggers when it senses an event. This triggering is what is of the most interest, although some sensors also output an analog measure of the alarm level. The second type of sensor is an environmental sensor, which continuously outputs a measurement of an environmental condition. An intrusion detection sensor will be referred to as a **sensor** or an **alarm sensor**, whereas an environmental sensor will be referred to explicitly as an **environmental sensor**.

Pwo kinds of alarms will also be referred to. A **raw alarm** is raised when an alarm sensor has been triggered by an event. Raw alarms are received by the control program only; the operator is never notified of raw alarms. A **true alarm** is raised by the control program after it has evaluated raw alarms and determined that an intrusion has probably occurred. All true alarms are relayed to the operator for assessment.

The phrase **sensor fusion** will be used to refer to two related but separate tasks. The first task is the fusion of environmental information with the alarm sensor information. This task is performed continuously to adjust the believability measure (weighting) of the sensors and to keep the operator apprised of the current confidence level of the RSS. The second sensor fusion task is the fusion of multiple sensor alarms into a single value which determines whether or not the operator should be alerted. This task is performed only when there have been one or more raw alarms within the past iteration of the control program.

3.0 Hardware

The RSS consists of a portable, multi-sensor pod connected by cable to a manned control console which contains an IBM PC and other processing hardware. An environmental monitoring station is also set up near the pod to send weather information back to the console. The pod and environmental station are set up outdoors in the location that security is needed, while the console is located in a command bunker up to a kilometer away. See Figure 1.

RSS SETUP

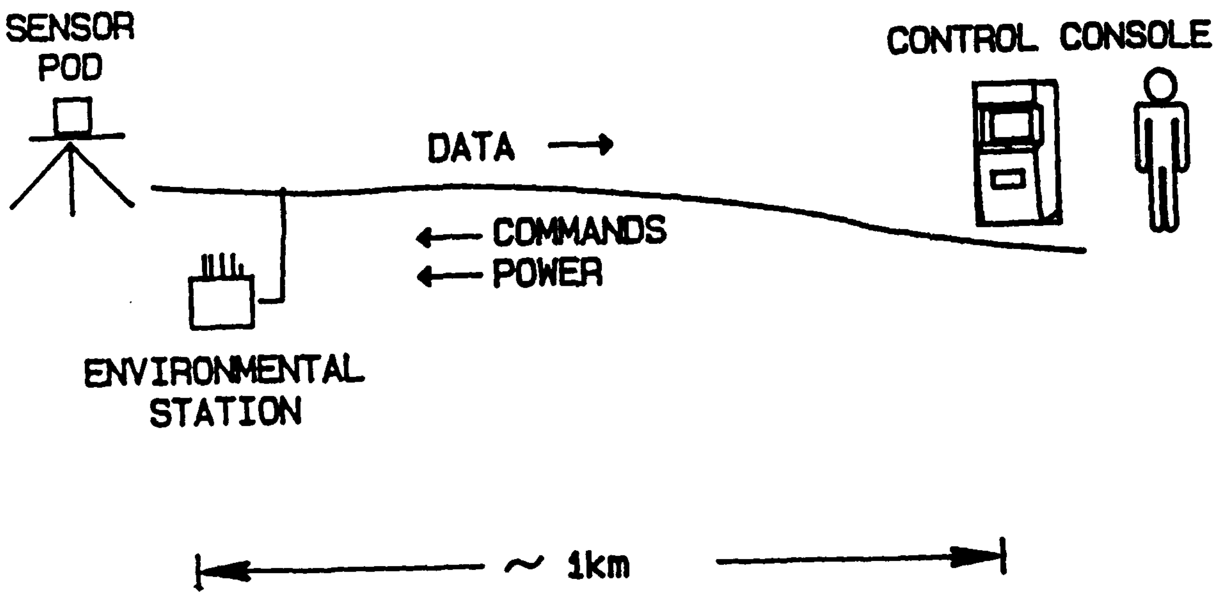


FIGURE 1

The pod and the console are major hardware units without which the RSS could not function. The RSS could still operate (at reduced efficiency) without the environmental station. The station provides information with which sensor confidence is updated. Should the environmental station be unavailable, there would be no filtering of alarm information from the intrusion detection sensors, and the operator would be alerted to all raw alarms.

A more detailed description of each of these three units follows (see Table 1).

Table 1. Equipment Lists

Pod	Control console	Environmental station
PIMS	PC-XT computer	Thermometer
VMD	Computer monitor	Barometer
Acoustic array	B/W video monitor	Hygrometer
CCD camera	Graphics monitor	Anemometer
IR spotlight	Graphics tablet	Photometer
Directional mike	Processors	(Precip. detector)

3.1 Pod and Intrusion Detection Sensors

The system's intrusion detection sensors are mounted on a motorized pan/tilt assembly on a tripod. This entire unit is called the **pod**. Three sensors are used in the current implementation: a passive infrared motion sensor (PIMS), a video motion detector (VMD), and an omnidirectional acoustic array.

The PIMS is an infrared device which senses target lateral motion. It compares the readings received in its two side-by-side detection fields, and it triggers if the readings differ. An analog output from the PIMS is also available but not used by the RSS. This analog level is a measure of the PIMS's current activation. The PIMS is a unidirectional device that can register events only in the direction that the pan/tilt assembly is pointed. The field-of-view (FOV) of the PIMS is about 6 degrees.

The Video Motion Detector (VMD), as its name implies, is a visually-oriented device. It processes the video from a CCD camera on the pod and determines if there is purposeful motion (change) across preset detection zones. The VMD is also a unidirectional device, as it receives its input from the camera. The camera's FOV depends on the current zoom of the lens and ranges from about 10 to 30 degrees.

The acoustic array processes the signals received from three microphones placed at the points of an equilateral triangle at the pod location. It can track one target at a time by using a beam-forming algorithm on the microphone signals. The beam-forming algorithm compares signal strength to a predetermined threshold and raises an alarm when the threshold is exceeded. The array is an omnidirectional sensor.

Other equipment mounted on the pod includes an infrared spotlight and a directional microphone, both of which serve as assessment aids.

3.2 Control Console

The control console houses an IBM PC-XT computer, a color computer monitor, a black-and-white video monitor, a graphics monitor, a graphics tablet, and the processors for the acoustic array and the VMD. The pod control program runs on the PC-XT. The PC monitor is used to display status information while the video monitor provides video to the operator for assessment purposes. The graphics terminal and tablet are used to display site maps and to input or edit these maps.

3.3 Environmental Monitoring Station

This station is a package of environmental sensors which include instruments to measure temperature, barometric pressure, humidity, wind velocity, and light level. These environmental sensors were part of an existing package and will not necessarily comprise the final mix when the RSS is fielded. For instance, a precipitation dectector will be added, while the barometer and hygrometer will probably be deleted.

The information from the environmental sensors is relayed to the control program running on the console computer, where it is used by the sensor fusion code to adjust the weighting of the intrusion detection sensors.

4.0 Control Program

The control software running in the console computer serves several functions. First, it serves as the interface between the human operator and the equipment. The software relays operator commands, such as pan or tilt directives, to the pod and relays alarm and status information back to the operator at the console. Second, the software serves as an operator's associate which makes a pass over alarm information to filter out false alarms.

Within the control program is a main loop which cycles approximately four times each second. In each iteration of the main loop, the control program performs housekeeping activities, polls the sensors, updates environmental information, and updates the sensor weightings.

5.0 Rationale for Weighting/Threshold Scheme

Whether or not the operator is ultimately notified of an alarm is a function of how many and which sensors alarmed and in which direction they registered. In a security system which does not use any filtering, ALL alarms would be relayed to the operator. The RSS, however, filters some alarms if they are raised in a low priority location or are from a low-believability sensor. Measures of area priority and sensor believability are maintained by the control program as wedge thresholds and sensor weightings, respectively. This is expanded upon in the following sections.

6.0 Wedge Thresholds

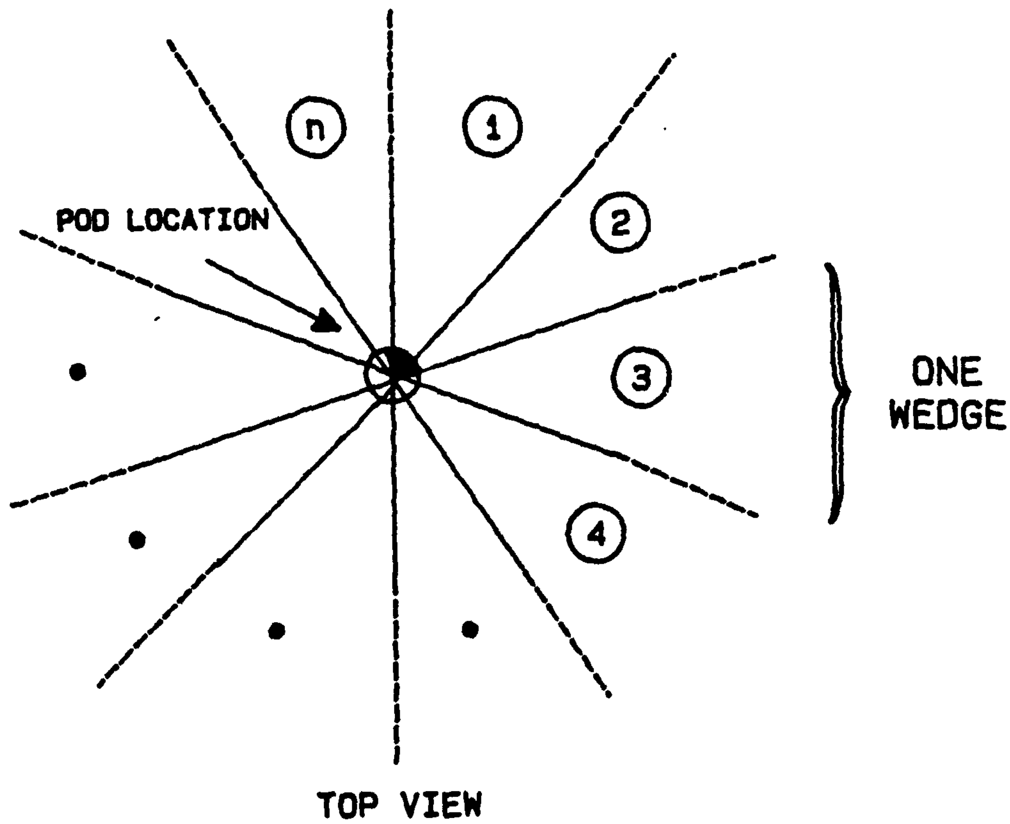
The area around the pod is divided into a number of wedges which radiate outward from the pod's location (see Figure 2). In the current control program implementation, there are ten uniform wedges, each spanning 36 degrees. The operator assigns to each wedge a threshold value from 0 to 100, inclusive, to reflect the importance of that area. The threshold values are inversely proportional to an area's importance. An operator can therefore assign values of nearly 100 to mask out a low-importance area. Conversely, he may assign low values to denote a high-importance area. The threshold values generally remain constant while the RSS is operating, but operator may adjust them if necessary in response to changing conditions. When the RSS is actually fielded, the allowable range of the threshold values may be decreased so that an operator can never completely mask out wedges and thereby defeat the purpose of the system. Alternatively, supervisors may be the only ones allowed to change the thresholds.

7.0 Sensor Weightings and Weighting Functions

The believability of a given alarm sensor is represented in the control program as a weighting for that sensor. This weighting is proportional to the sensor's believability. Environmental conditions are one factor which influence a sensor's believability as an alarm received from a sensor under adverse weather conditions is more likely to be a false alarm than one received under ideal conditions. In other words, as environmental conditions degrade, the believability of sensors also decreases.

Figure 2

WEDGE DEFINITION



To reflect the influence of weather on the sensors, the control program calculates a weighting for each sensor based on the current environmental conditions. This weighting ranges from 0 to 100 inclusive and is proportional to the sensor's believability. The operator cannot adjust a sensor's weighting.

Associated with each sensor is a weighting function which calculates the sensor's weighting based on the current environmental conditions. Individual functions are needed for each sensor since each is affected by different environmental conditions. The functions currently being used are preliminary, as very little field testing has been done to determine the exact effect of the environmental conditions on each sensor. As a first approximation, common sense and knowledge of the way each sensor operates were used to write simple weighting functions. It must be stressed that the current functions are preliminary and will probably be changed after testing is completed. Descriptions of the weighting functions are given in Table 2 and in the following paragraphs.

Table 2. Sensor Weighting Functions

Device	Function parameters	Relation of weight to parameters
PIMS	Temperature	Inversely proportional
VMD	Light, wind	Proportional to light, inversely proportional to wind
Array	Wind, rain	Inversely proportional

7.1 PIMS Weighting Function

Because the PIMS is an infrared device, it is affected adversely by high ambient temperature. The weighting function for the PIMS is of the form

$$wt_{PIMS} = f(\text{temperature})$$

where the weighting is inversely proportional to the temperature. As the temperature rises, it becomes more difficult for the PIMS to detect the difference between a target's temperature and the background temperature. Therefore, as the ambient temperature rises, the believability of the PIMS decreases since the probability is greater that an alarm has a spurious cause.

7.2 VMD Weighting Function

The VMD weighting function is of the form

$$wt_{VMD} = f(\text{light, wind})$$

where the weighting is proportional to light level and inversely proportional to wind velocity. Low light level affects the performance of the VMD since changes in the scene become more difficult to detect as ambient light decreases. High light levels are not a problem since the automatic iris on the camera zoom lens preserves high contrast.

7.3 Acoustic Array Weighting Function

The RSS does not have a noise meter, but the presence of some continuous noise may be inferred by examining wind velocity. Wind blowing across the microphones will confuse the array's tracking algorithm. The form of the weighting function for the array is thus

$$wt_{array} = f(wind, rain)$$

where the weighting is inversely proportional to wind velocity. Note that the sound of falling rain can similarly confuse the array, and so a precipitation detector will be included in the next environmental station.

8.0 Raw Alarms

When either the PIMS or the VMD is triggered, it sends a single character back to the console computer. The acoustic array sends back a number indicating the compass direction in which it detected a target, if any. (Alarm direction from the PIMS and VMD does not need to be sent because these two sensors are unidirectional and alarm direction is the same as current pan angle). A sensor sends information to the console computer only if the sensor has been triggered. At each iteration, the control program polls all three sensors for raw alarms. If there have been any, the control program initiates the determination of whether the operator should be apprised of the situation.

9.0 Action Upon Receiving Raw Alarms

When one or more raw alarms are received, the control program determines if the operator should be notified of the event. Sensor fusion is used to merge the information of multiple alarms. For each wedge, the following is calculated:

$$wt_{total} = W_1 + W_2 + W_3 + \ldots + W_n$$

where the W_i are the weightings of the sensors that triggered in this wedge. This sum is then compared to the threshold value for that wedge. If the sum exceeds the threshold, the control program raises a true alarm and the operator is notified. If the

sum is below threshold, then no alarm is raised and the operator is not notified of the event. The sum of weightings is used for ease in combining the information from more than one sensor, on the principle that two or more heads are better than one; i.e., if more than one sensor triggers in a given wedge, the probability is greater that this is a true alarm.

When the operator is notified of a true alarm, he must view the location of the event and render an assessment. The three possible alarm assessments are Real, Nuisance, and Unknown. Real alarms are those which have discernible, threatening causes, such as a column of armored vehicles. A Nuisance alarm also has a discernible cause, but it is nonthreatening like a rabbit. Alarms classified as Unknown have no apparent cause and may indicate a hardware failure. Alarm statistics are stored each time the operator makes an assessment. This information includes the assessment rendered, sensor(s) and wedge involved, wedge number, strength of alarm (total weighting), and the time of the event. Temporal information such as this will be used in later versions of the weighting functions.

10.0 Results and Discussion

Since the RSS is still in the developmental stage, little testing has been done. It appears that the FAR is decreased by masking out wedges (giving them high threshold values). However, the PD is consequently decreased since all alarms are masked out before they can be processed.

The RSS must undergo extensive testing under diverse weather conditions before any conclusions may be drawn about the accuracy of the weighting functions in calculating sensor believability. It is expected that the functions will be an effective means of filtering out false alarms. Withrespect to the fusion of the information of multiple alarms, it seems that the weighting/threshold algorithm is effective in combining the results of two or more sensors which trigger. For instance, the VMD was observed to trigger occasionally on some random distortion in the video image. If the wedge threshold is set to a high value, then the raw alarm will not have enough weight to raise a true alarm, and this false alarm is filtered. The PIMS triggers on the same sort of phenomenon that the VMD does (change in scene due to motion), but it relies on infrared information. When both the VMD and the PIMS triggered at the same time there was usually an actual event as "sightings" were made in both the visual and thermal spectra. The sum of the weightings of the VMD and PIMS usually exceeded the wedge threshold, and a true alarm was raised as desired. Triggering on an event from different sensors is an excellent indication of a true alarm, and the weighting/threshold effectively represents this by the summation of the weightings of all the raw alarms in an area.

11.0 Future Work/Recommendations

With respect to sensor fusion in the RSS, future work may be aimed in two directions: writing new weighting functions which take advantage of field-test results and temporal information; and use of code and specialized hardware for recognizing patterns in the sensor data.

11.1 New Weighting Functions

Extensive testing of the RSS must be done under diverse weather conditions. This is of major importance for refining the weighting functions to accurately calculate the believability of sensors in various environments.

The believability of a sensor is based not only on the current environmental conditions, but also on the performance history of the sensor. The weighting functions will be modified to consult temporal information (stored alarm statistics) to find patterns and trends.

11.2 Pattern Recognition

Some improvement in performance may be gained by using new weighting functions. However, such modification can increase the RSS performance only up to a certain point. As the functions become more complicated, a greater the percentage of processor time will be spent executing them.

This amount of time could become prohibitively great if the number of sensors deployed on the pod is increased as expected. Also, there exist history patterns which cannot be discerned in any algorithmic way. Upgrading the hardware, such as by employing a parallel architecture, can solve the problem of processor load. However, the pattern recognition problem requires a completely different approach in software. In general, the RSS produces a single output from a large number of inputs, a number which will increase when temporal information is used and more sensors are added. This type of problem is ideal for solution by a neural network. Therefore, to increase RSS performance considerably, a neural network implementation may be investigated to augment the weighting/threshold sensor fusion algorithm.

12.0 **References**

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